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Changes in Corn Quality

During Export from New Orleans to Japan

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Lowell D. Hill, Marvin R. Paulsen, Barry J. Jacobsen, Richard L. Vanderlip

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Bulletin 788A

COMPANION TO THIS VOLUME

This research report is available in a twenty-page *Summary Version* illustrated with color photographs. The summary version focuses on courses of action to improve the quality of corn that importers receive. Order Bulletin No. 788B, *Changes in Corn Quality During Export from New Orleans to Japan: Summary Version.*

Changes in Corn Quality

During Export from New Orleans to Japan

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Bulletin 788A ❧ College of Agriculture

University of Illinois at Urbana-Champaign

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Introduction

Changes in the quality of corn between U.S. origins and foreign country destinations have been a frequent explanation of complaints by foreign buyers about low quality in their processing plants. Since quality at the time of loading is certified by federal inspectors, and on the average is above the minimum quality requested by the foreign buyer [9], the problem has been presumed to be caused by handling and shipping practices. Past studies have shown that the number of broken kernels (recorded as BCFM in U.S. corn grades) increases during loading and unloading of the vessel after the grade is certified [2, 3, 4, 5] and that heating of the corn can occur during transit on the ocean, especially through warm waters [8]. This study was designed to (a) establish the extent of quality-loss under different environmental conditions, (b) identify the causes of quality-loss, and (c) suggest possible solutions to reduce the loss of quality during shipment.

Two shipments of corn, both bound from U.S. ports in the New Orleans area to Japanese ports, were selected for this study. The first was loaded in May 1985, the second in March 1986. By coincidence, the same vessel was nominated for both shipments. Different exporters, buyers, and final users were involved in each shipment; this diversity offered a useful range of technology and loading conditions but added to the complexity of organizing identical tests and sampling procedures.

The identity of the corn in the 1985 shipment was maintained from the outbound belt at export to the barges in Japan, and samples were taken at each point where the grain was handled physically or transferred. In the 1986 shipment the identity was maintained from each barge loaded at midwestern river elevators to the barges and coasters in Japan. Origin quality in the barges loaded at river elevators in the 1986 shipment was based on records provided by the river elevators. All other data were based on samples obtained under supervision of the researchers, supplemented by quality data reported by the Federal Grain Inspection Service of the USDA, the Japan Grain Inspection Association, and the export elevator.

Organization of the Study

A comparison of corn quality at origin and destination, based on extensive sampling, requires the cooperation of many firms and individuals. The first step was to obtain a commitment from the Japanese importers, who selected the export elevator and nominated the vessel. A commitment of time, resources, and cooperation was essential. Many other people and agencies were involved in implementing the research plans:

- in Japan, customs officials, stevedores, inspection agencies, the quarantine authority, and a team of Japanese samplers;
- in the United States, the Federal Grain Inspection Service (FGIS), export brokers, plant managers, stevedores, and the Animal Plant Health Inspection Service (APHIS), which provided permission to return samples to the United States; and
- on the vessel, the owners of the vessel, the captain, and the chief engineer.

Questions of insurance, liability, customs clearance for equipment and personnel traveling into and out of both countries, safety with respect to the installation of equipment and the logistics of personnel and equipment (e.g., before the loading, 4,000 feet of temperature cables were cut to lengths to match the location of each sensor) all added to the complexity of planning and implementation. Any delays in loading that resulted from sampling or from the installation of equipment represented large financial losses to the exporter. Logistics, sequencing, and speed with safety were all given high priority.

Before loading of the vessel, the research team, stevedores, the plant manager, the ship's master, and FGIS personnel met to facilitate the coordination and sequencing of loading and sampling. The required grain depth for sampling needed to be coordinated with the stowage plan in each hold, the balance of weight and pressure among holds in the vessel, the loading schedule of the elevator, and the schedule of stevedore shifts. The success of the sampling program required a willingness to adapt and adjust. The selection of holds for sampling had to be adjusted to match all the factors above. The timing of sampling and analysis in the elevator, on the outbound belts, and from the inbound barges was scheduled to keep a full sampling team available in the hold; twenty minutes was often the maximum time available for sampling, bagging, and tagging sixteen two-probe samples. Accurate records and identification of every sample had to accompany all of this activity.

Similar coordination and planning was required when the vessel reached its destination. Before the vessel arrived in its berth, all sampling and analysis was coordinated with stevedores, inspection agencies, and elevator managers. When the vessel was several hours from the harbor, the vessel masters were contacted by ship-to-shore communications to plan the unloading sequence of each layer and each hold. Receivers, as well as barge owners and operators, were contacted for permission to take samples of their grain. More than one destination was receiving grain from the vessel, and the logistics of which holds were to be sampled in which sequence without creating imbalance on the vessel added to the complexity. Pneumatic unloaders had to be removed from the hold at each 10-foot level before the sampling team could enter the hold. And in 1986, after all plans were finalized, a typhoon required the vessel master to close the hatches and move back out to sea. This disrupted the entire sequence and generated a second round of adapting research plans to the complex world of moving corn from vessel to barge.

Despite this difficult and shifting planning process and the associated negotiations, the researchers did not compromise the important basic principles: (a) samples had to be representative of the sublot from which they were taken; (b) sample identification had to be kept inviolate and the samples kept intact; (c) samples had to be selected randomly and without bias with respect to quality; (d) analysis

had to follow established laboratory procedures and statistical principles; and (e) the objective of origin-to-destination comparisons had to be fulfilled by matching holds and samples. The cooperation and adaptability on the part of everyone involved in the research made the project exciting and rewarding, and helped provide answers to the questions posed at the beginning of the project.

Sampling Procedures

Researchers obtained samples at each location in the market channel: from the inbound barges during unloading at the export elevator (only in 1986); from the mechanical cross-cutting diverter on automatic timers in the export house; from the vessel during loading, using 10-foot compartmentalized grain probes; and from the vessel, barges, and coasters in Japan, using the same grain probes. The source of each sample was recorded, and the corn was sealed in a plastic bag and sent to the University of Illinois Agricultural Engineering Grain Quality Laboratory (AEGQL) for cold storage until tests could be completed. Some analyses were completed on site during the sampling to preclude the possibility of quality changes in the corn while it was in transit from Japan to the University of Illinois.

Sampling rates and patterns were selected to provide the most accuracy and to minimize the possibility of bias, within the restrictions imposed by time, costs, and the configuration of vessels and barges. Barges at the export elevator were sampled during unloading using diverter samplers, which take approximately 125 g from a cross-section of the full grain-stream at intervals determined by a timer. Several hundred "cuts" of the diverter were composited into one sample per barge. Elevator personnel controlled the operation of the sampler according to USDA procedures. Samples from the outbound belt were obtained from a similar automatic sampler under the supervision of FGIS. A composite sample from every 15,000 bushels was sent to the University of Illinois.

The only acceptable method for sampling in the hold of the vessel was with grain probes. Official sample analysis requires a minimum of 1,600 g; a two-probe sample provided approximately 1,800 g of corn. Therefore, except for an intensive single-probe sampling in one hold to determine variability extremes, each sample consisted of the contents of two probes. Each hold was divided into 16 sectors, and the two-probe samples were taken at random locations in each sector. Because the probes were 10 feet in length, each hold was sampled in layers after loading approximately 10 feet of grain. Barges and coasters in Japan were sampled with 10-foot probes following the official pattern developed by the USDA for obtaining representative samples from barges.

Duplicate analyses by other agencies and laboratories were performed on some samples to verify accuracy, repeatability, and representativeness of the samples and to provide supplemental information. All samples were tested at the University of Illinois AEGQL. Selected tests on grade factors were performed by the Federal Grain Inspection Service (FGIS) of the USDA at its Lutcher office in Louisiana; by the Japan Grain Inspection Association (JGIA) in Chiba, Japan; and by the Champaign-Danville Grain Inspection Department (CGID) in Champaign, Illinois. In the 1986 test, analyses for mold and insect infestation were performed on site and at the University of Illinois Entomology and Plant Pathology laboratories, using a randomly selected portion of samples collected at the origin and destination. In the 1986 test, insect-infestation levels were assessed at loading and again at destination to determine any increase in detectable insect numbers following a 4-week incubation period during transport.

Changes in the corn's quality between the various points in the market channel were estimated by comparing the results of these analyses, on the assumption that the various sampling procedures yielded equivalent results. Previous research has indicated that analytical results may be influenced by the sampling method. For example, compartmentalized

grain probes generally result in higher levels of broken corn and foreign material (BCFM) than do diverter samplers [7]. Because both methods are accepted by the USDA for issuing grade certificates, however, no adjustments were made in the data from samples taken by diverter in the export house or from probe samples taken in the vessel and barges. The number of samples and the sampling procedures provided composite samples considered to be representative of the bulk grain lot from which the samples were taken. The percentage of broken corn and foreign material (BCFM) was determined by the Carter-Day dockage tester in all tests performed by the Federal Grain Inspection Service (FGIS). The Gamet shaker, with 12/64-inch sieves and 30-stroke cycles, was used to determine BCFM at the University of Illinois AEGQL. Results from the two testing methods differ, but no adjustments were made in the BCFM data. Statistical tests were used to identify significant differences in quality. The 99 percent level of probability was used for all comparisons, except as noted in the text and tables.

Sampling at Origin

In 1985, the vessel *Century Progress* was loaded with 56,895 metric tons (2.24 million bushels) of U.S. No. 3 yellow corn; in 1986 it was loaded with 55,006 mt (2.17 million bushels). Maximum moisture was 15.0 percent on both contracts. No additional quality factors were specified in the contracts.

In the first test the vessel was loaded May 22 and 23, 1985, in the New Orleans port area and arrived June 28 in Chiba, Japan, via the Panama Canal and Long Beach, California. The second test followed a similar path but took slightly less time in transit. In the second test the vessel was loaded March 20 and 21, 1986, in the New Orleans port area and arrived April 22 in Kashima, Japan. The 1985 experiment started at the export elevator with official samples from the diverter sampler taken during loading of the vessel. FGIS provided duplicate samples from each 15,000-bushel (381 mt) component used to construct the official 60,000-bushel (1,524 mt) sublot sample. The FGIS loading log provided inspection information on each sublot. Samples were taken with grain probes from holds 5 and 6 from each of the 16 sectors in 10-foot layers according to the pattern shown in Figure 1. The width and length of each hold were divided into four equal parts and identified by letters and numbers. A sample consisted of the corn from two probes taken in each sector in each layer. Each sample was bagged and identified by sector, layer, and time of sampling. All five layers were sampled in hold 5; only the bottom three layers were sampled in hold 6 (see Table 1).

Data collection from the 1986 shipment started farther back in the marketing channel. Origin data were provided on 41 barges that were inspected when they were loaded at midwestern river elevators. Export-elevator personnel used diverter samplers to sample 40 of these barges and record the grade information; the remaining portion of each sample was split using a Boerner divider, and approximately 2,000 g of each were sent to the University of Illinois. AEGQL received intact samples from 39 of these barges. The grain from each barge was placed in a separate bin as it was unloaded, to preserve its identity so that the loads could be blended to the correct contract specification. FGIS obtained official samples from each 30,000-bushel (762 mt) component, using a diverter sampler located on the belt between the storage bins and shipping bins. Samples from the two components were composited to provide an official sample for the inspection log for 60,000-bushel (1,524 mt) sublots. After the corn was loaded into the *Century Progress*, samples were taken in 10-foot layers in holds 1, 3, 5, and 7 (see Table 1). After a 10-foot layer was loaded, the loading spouts were moved to another hold while that layer was sampled. After the sampling of each layer was completed, the spouts were returned to the test holds. In holds 3, 5, and 7, two-probe samples were taken from each of the 16 sectors in each layer (see Figure 1). Hold 1 was sampled using single-probe samples from each of 36 sectors per layer to provide more detailed information on segregation of quality within the hold (see

Figure 1. Two-probe sampling patterns for each layer, New Orleans to Japan, 1985 and 1986.

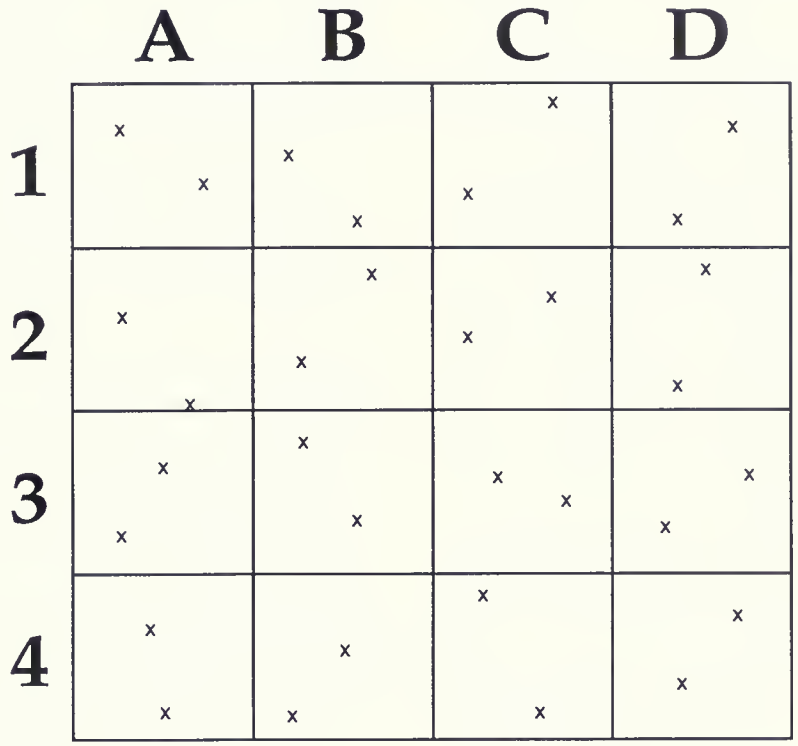


Figure 2. Single-probe sampling patterns for each layer, New Orleans to Japan, 1985 and 1986.

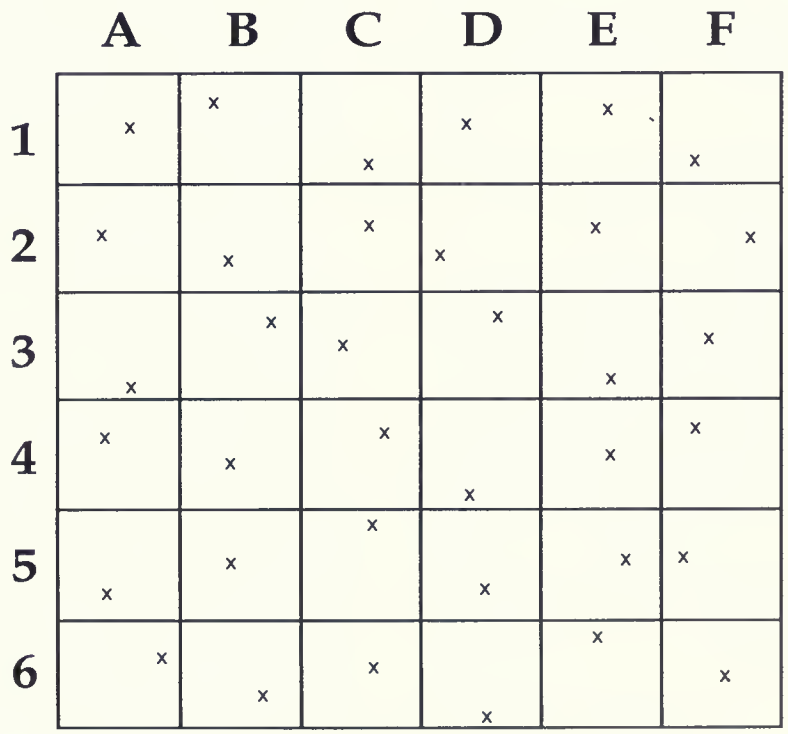


Figure 2). Once the hold was filled, there was not enough space between the corn surface and the deck to permit sampling the 20 sectors on the perimeter of hold 1 using the 36-sector sampling pattern. Only the center 16 sectors were sampled in the top 10-foot layer in hold 1.

The moisture variability within the samples was evaluated by measuring the moisture of 48 individual kernels selected at random from each sample during the loading process. One cut of the diverter sampler (approximately 125 g) was taken as a sample from which to randomly select 48 kernels. Each kernel was hermetically sealed in a glass vial. Later, the air-oven method was used to determine the moisture content of individual kernels in samples selected from five inbound barges in the 1986 shipment and in five samples taken from the conveyor belt during loading of the 1985 and the 1986 shipments.

A 250 g sample was selected randomly from each probe and diverter sample for mold analysis in the 1986 shipment. Each sample was mixed with a calcium carbonate drying agent, sealed in plastic bags, and sent to the University of Illinois Plant Pathology Department. A sample of 100 whole kernels was selected randomly from each bag for plating to determine the kind and frequency of the various molds.

Temperature and humidity sensors were placed in hold 5 in both shipments. This hold was filled to capacity. In 1986, sensors were also placed in hold 6, which was filled to approximately three-fourths capacity. The sensors in hold 5 were arranged to determine the extent of temperature changes on the side of the vessel (above and below the water line), on the bottom of the vessel over the fuel tanks, at the surface of the grain, and in the corn mass (to determine how far any surface temperature changes would penetrate into the bulk). Figure 3 shows the placement of the sensors in hold 5 for the 1986 shipment. In 1986, sensors were also placed on the surface and at depths of 1, 3, 5, 7, and 10 feet in hold 6 to determine the effect of the greater air space above the corn in the slack hold. Sensor placement in 1985 was similar to that in 1986, except that the 10-foot depths were not used. The temperature and humidity sensors were connected to a recorder that automatically measured temperatures and humidities every half hour, averaged these measurements every two hours and stored the two-hour information in memory for periodical transfer to a tape. This system operated continuously from the time the vessel was loaded until the recorder was removed just before the grain was discharged in Japan.

Sampling at Destination

The holds selected for sampling differed between the origin and destination, to obtain the maximum range of information with a minimum of sampling time at each location (see Table 1). Only hold 5 was sampled in an identical manner at the origin and destination of both shipments, to determine if the results were consistent with the conclusion from previous studies that moisture and grade factors other than damage do not change in the vessel between the origin and destination. At the destination the sampling pattern shown in Figure 1 was followed for all layers of hold 5, layers 1 through 4 of hold 6, and layers 1, 2, 4, and 5 of hold 2 in the 1985 shipment; the sampling pattern was followed for all layers of hold 5 and layers 4 and 5 of hold 3 in the 1986 shipment. In the 1985 shipment, layer 3 of hold 2 was sampled using the single-probe pattern shown in Figure 2. In the 1986 shipment, corn temperatures at destination were measured with a portable temperature-sensor to check for "hot spots" on the surface and to check the depth of penetration of any increase in temperature. Samples were taken from hot spots in holds 1, 2, and 3 with a 6-foot probe. The probe was emptied by compartment so that two of the 6-inch compartments comprised a sample. This technique provided samples representing depths of 0-1, 1-2, 2-3, 3-4, 4-5, and 5-6 feet.

Each sample was analyzed for the total number of damaged kernels and the percentage of kernels showing fungal infestation. The same sampling method was used to obtain samples in one-foot increments from the top five or eight

Figure 3. Placement of temperature sensors in hold 5 of the *Century Progress* in New Orleans.

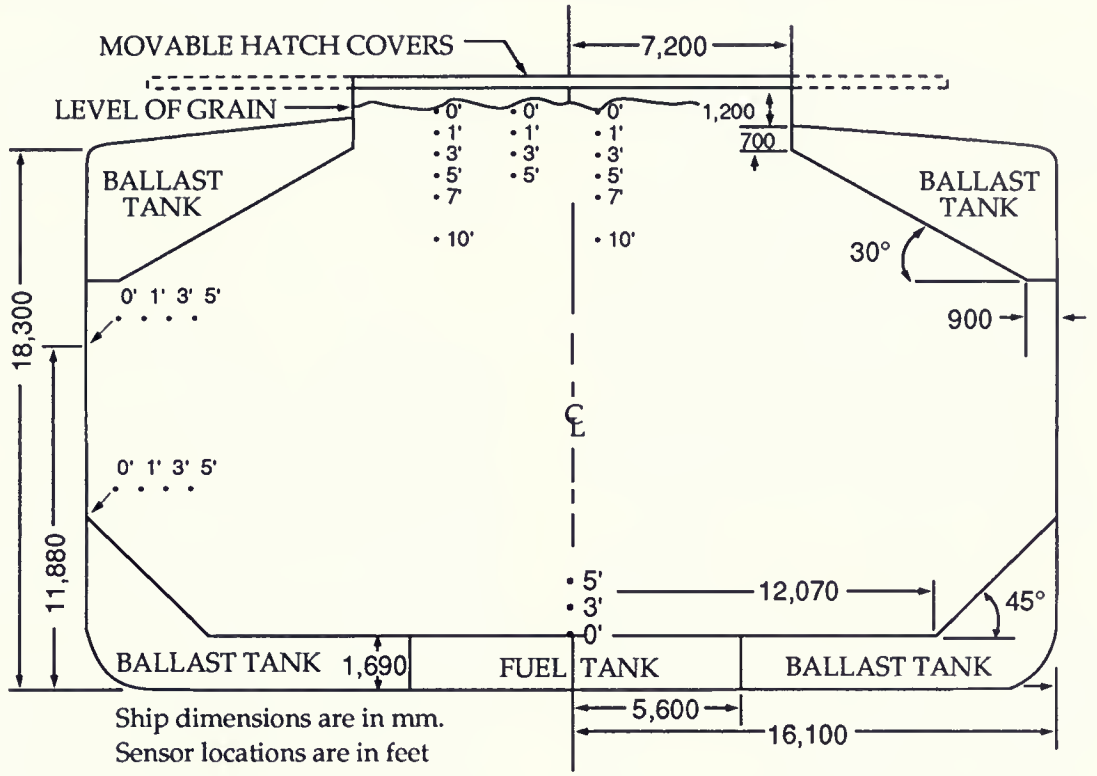
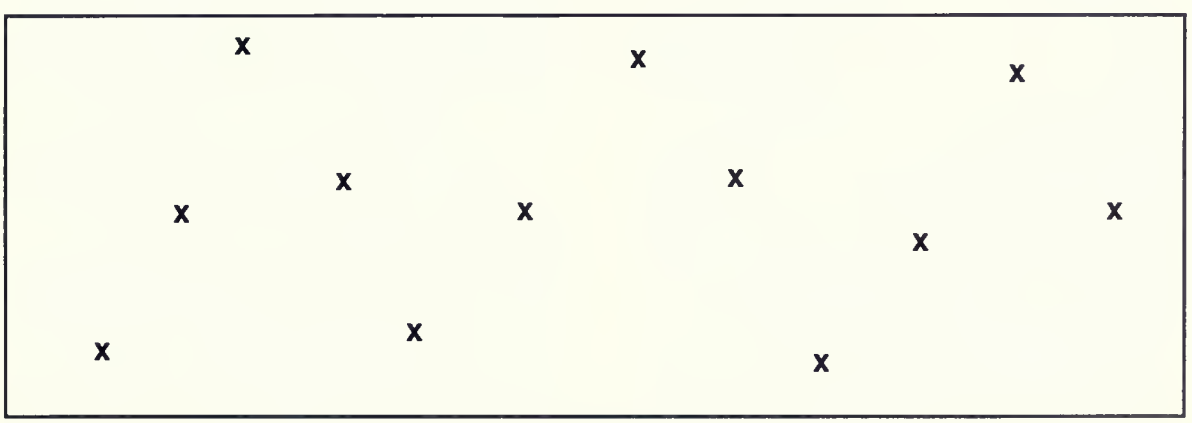


Figure 4. Sampling patterns for barges and coasters in Japan. (Fewer samples were taken in barges than in coasters.)



feet of holds 5 and 7 following the sampling pattern shown in Figure 1. Each of the sixteen samples from hold 6 were divided using a Boerner divider; half of each sample was analyzed for moisture by the Japan Grain Inspection Association (JGIA), and the other half was sent to the University of Illinois. All two-probe samples from hold 5 were split, and half of each sample was used for a composite sample. Each composite contained samples from four sectors of one quadrant in each layer. Each of the five layers therefore generated four composite samples, for a total of 20 composite samples from hold 5. Each composite sample was split and half of each sample was sent to the Champaign-Danville Grain Inspection Department for grading and determination of the percentage of damaged kernels. The other half of each composite sample was analyzed by the Japan Grain Inspection Association to determine broken corn and foreign material (BCFM) using a Carter-Day dockage tester equipped with a 12/64-inch sieve, following procedures similar to those of FGIS.

In 1985 some of the corn from the vessel was unloaded directly into barges, and the balance was moved into storage silos. Samples could not be obtained from the silos, but four barges were selected at random for sampling with 10-foot probes using a zigzag pattern (see Figure 4). Six probes were taken from each barge. The 1986 shipment was unloaded into larger vessels called coasters, as well as into barges and storage silos. Three coasters were selected for sampling, and twelve single-probe samples (see Figure 4) were taken from each of the coasters, which were loaded directly from the vessel using pneumatic unloaders. A composite sample was obtained from each coaster for an official grade determination.

For both shipments the analysis of the moisture content of individual kernels at destination was based on random samples taken from the hold during unloading or from trucks or coasters after unloading. In 1985 the samples were bagged and sent to the Agricultural Engineering Laboratory at the University of Illinois for single kernel analysis. In 1986, 48 individual kernels were selected during unloading, sealed in glass vials, and sent to the University of Illinois for analysis. A portion of each of the probe samples from the vessel was mixed with a calcium carbonate desiccant, sealed in a plastic bag, and sent to the University of Illinois Plant Pathology Laboratory for mycological analysis.

Sample Analyses

Tests on the corn were performed at the Agricultural Engineering Grain Quality Laboratory (AEGQL) and Plant Pathology Laboratory at the University of Illinois, the Champaign-Danville Grain Inspection Department (CGID), and the Japan Grain Inspection Association (JGIA). AEGQL tested the corn for test weight, bulk moisture content, individual kernel moisture content, broken corn and foreign material (BCFM), breakage susceptibility, particle size, stress cracks, kernel density, and percentage of whole kernels. The Plant Pathology Laboratory identified the kinds of fungi and determined the percentage of kernels infected with mold. CGID determined the grade of each composite sample. In the 1986 shipment, CGID also determined the percentage of total damaged kernels (DKT) on samples obtained from the hot spots found in holds 1, 2, and 3. DKT was determined on board the vessel immediately after the samples were drawn, to avoid the possibility of changes in damage before the samples reached the University of Illinois. JGIA ran moisture tests and BCFM tests on samples provided from both cargos; the tests provided a preliminary report in Japan and determined if BCFM or moisture content changed during shipment of the samples by plane from Japan to the University of Illinois.

Moisture Content

Although moisture content is no longer a grade factor, moisture in corn is a major factor affecting its storability during transport. AEGQL and JGIA measured moisture content by

placing preweighed samples in an air-oven maintained at 103° C for 72 hours (method AACC 44-15A). After cooling, the samples were weighed again, and the weight loss was divided by the original weight to calculate the percentage of moisture in each sample. CGID used a Motomco moisture meter to determine moisture content on the samples they analyzed.

Particle Size and Percent of Whole Kernels

AEGQL determined particle size based on a portion of each sample, obtained by using a precision divider. One-fourth to three-eighths of each sample (using a sample weighing between 200 and 300 g) was placed on a Ro-Tap sieve shaker. The Ro-Tap shaker contained six U.S. standard square mesh sieves ranging in size from $^{20}/_{64}$ inch to $^{3}/_{64}$ inch. The sieves were stacked in descending size with a solid pan under the $^{3}/_{64}$ -inch sieve. The corn was placed in the top sieve, and the Ro-Tap vibrated the sieves for two minutes. The amount of corn retained on each sieve was weighed and divided by the original weight of the total sample to obtain a percentage of the sample retained by each sieve. The percentage of whole kernels was calculated by manually separating the whole kernels in a representative sample (50 g) and dividing the weight of the whole kernels by the initial weight.

Broken Corn and Foreign Material (BCFM)

BCFM tests were conducted at the University of Illinois using 30 cycles on a Gamet sieve shaker with a $^{12}/_{64}$-inch sieve. The material passing through the sieve and the noncorn material, separated manually from the top of the sieve, were combined and weighed. These weights were divided by the initial weight to determine the percentage of BCFM. JGIA and CGID used an official Carter-Day Dockage Tester for determining BCFM. Roughly 1,000 g of corn were placed on a vibrating, slightly angled, $^{12}/_{64}$-inch sieve to screen the fine particles through to a pan, and they were weighed. Material retained by the sieve was vibrated into another pan and weighed.

Breakage Test and Stress Cracks

Breakage susceptibility of the corn was tested using the Wisconsin breakage tester, manufactured by the Engineering Department of Cargill, Inc., in Minneapolis, Minnesota. A 200 g sample was prescreened with a $^{16}/_{64}$-inch sieve, weighed, and placed in the breakage tester. The tester consisted of a centrifugal impeller rotating at 1,800 rpm that threw the corn against the inside surface of a vertical cylinder. The weight of the sample passing through a $^{16}/_{64}$-inch sieve after the breakage test was divided by the initial weight to determine the corn's susceptibility to breakage, expressed as a percentage.

The percentage of kernels with stress cracks was determined by visual examination. Fifty whole kernels were selected randomly from each sample, and a light-candling method was used to identify stress cracks visually. Kernels were grouped according to their number of stress cracks—none, one, or several. The number of kernels in each category was converted to a percentage of the 50 kernels.

Density

True density was determined using the ethanol column test. One hundred preweighed kernels were placed into a graduated cylinder containing ethanol, and the volume of the corn was calculated by measuring the volume of liquid displaced by the added kernels. The weight of the sample divided by the volume gave the average kernel density in grams per cubic centimeter. Density was also recorded in pounds per bushel using the standard test weight device.

Determination of Insect Infestation Levels (1986 Only)

Entomologists examined screenings from 80 samples collected at New Orleans from holds 1 and 5. In addition, twelve Grain-Guard insect traps (perforated plastic cylinders that serve as

pitfall traps) were placed just below the grain surface in three holds immediately following loading of the vessel. The traps provided a sensitive means of detecting insects if grain temperatures exceeded approximately 15°C (approximately 60°F).

The Grain-Guard traps were removed from the corn immediately after the holds were opened April 23 and 24, 1986. Japanese inspectors screened and examined samples from the surface of each hold; samples collected from hold 5 were also examined for insects.

Mold Identification (1986 Only)

The identification of molds and fungi and the percentage of kernels colonized were based on 100 randomly selected kernels from a representative sample stored in calcium carbonate to prevent further mold growth until the samples could be plated in the laboratory. In addition, several samples were plated on site to verify the accuracy of the control procedure. Whole kernels were plated using a sterile technique on malt-salt agar [1] after surface sterilization in 0.5 percent sodium hypochlorite for one minute. Plates were incubated for 7 days at 23 to 24°C. After plating, the percentage of kernels colonized by species of *Aspergillus*, *Penicillium*, or *Fusarium* was recorded for each sample collected at the origin and destination.

Results

The numerical grade of the corn at the destination was lower than the grade shown on the origin certificate. The quality-losses resulted from physical impacts during loading and unloading and from biological relationships that caused deterioration during the ocean voyage. Analyses of origin samples from hold 5 were compared with destination samples in both 1985 and 1986. There were no significant changes in the physical characteristics of the corn during transit after the vessel was loaded; sampling variability accounted for any observed differences in BCFM, test weight, whole kernels, particle size, and moisture. This is consistent with results from previous studies [2, 3, 4, 5]. Because there were no changes in these factors between the origin and destination, most comparisons in the following paragraphs treat the origin and destination samples from the vessel as if they were all taken from the vessel before discharge in Japan. Where the same hold was sampled at the origin and destination, values were averaged. The only grade factor analyzed for possible changes during transport was damage.

Changes in Grade Factors

The average grade for inbound barges (1986 only) was No. 2. The grade certified at the origin for both the 1985 and 1986 shipments was U.S. No. 3 or better on all factors. The average grade of both shipments decreased from U.S. No. 3 at origin to sample grade after unloading at the destination (see Table 2). The only factor reducing the grades at destination was high levels of BCFM. Changes in other grade factors were relatively small and would not have resulted in a change in numerical grade.

BCFM. The impacts kernels undergo during loading and unloading increase the amount of BCFM, as kernels or pieces of kernels are broken into particles that will pass through the $^{12}/_{64}$-inch sieve. The average BCFM of all barges in the 1986 shipment at the time of loading at midwestern elevators was 2.90 percent (see Table 2) with a range among individual barges from 2.0 to 4.4 percent. Unloading at the export elevator added slightly to the breakage, with an average of 3.10 percent determined by inspectors at the elevator. This increase was not statistically significant.

The *Century Progress* was loaded by spouts dropping the corn into the holds. In 1985 conveyor belts brought the corn directly from the storage bins to the vessel. In 1986 the corn was conveyed from storage bins to shipping bins, and then to the vessel. The impacts associated with each handling resulted in an increase in BCFM. In 1985, the loading log

recorded 3.45 percent BCFM in samples taken from the outbound belt (see Table 2). Samples taken from the vessel after loading showed 4.97 percent BCFM—a statistically significant increase of 1.52 percentage points. In the 1986 shipment, the loading log recorded 3.86 percent BCFM enroute to the shipping bins. This increased to 6.59 percent BCFM in samples from the vessel—an increase of 2.73 percentage points, also significant at the 99 percent level.

Before combining data for samples taken from the vessel at the origin and destination, the results for hold 5—selected for replication at destination in both years—were compared. BCFM in 1985 was 4.67 percent at the origin, 4.72 percent at destination. In 1986 hold 5 averaged 7.27 percent after loading at the origin, 7.32 percent at destination. These results for hold 5 at the origin and destination reinforce previous research that has shown no significant change in BCFM during transit. This conclusion makes it possible to combine origin and destination results on each vessel or to rely on samples taken at either location, depending on access to the hold.

Samples taken from the barges in Japan in 1985 after unloading by pneumatic equipment averaged 7.68 percent BCFM—an increase of 2.71 percentage points between the vessel and the barge (see Table 2). The 1986 tests showed an even greater increase during unloading—from 6.59 percent BCFM in the vessel to 9.28 percent BCFM in the coasters.* The increase was statistically significant in both cases. Comparisons between the vessel and the coasters or barges are based on identical sampling and analysis.

Test weight. Test weight in the 1985 shipment increased from 55.75 pounds per bushel on the inspection log to 55.91 pounds per bushel in the vessel. Test weight also increased between the vessel and the destination barges. The changes were not statistically significant. In 1986, test weight increased from 56.43 pounds per bushel on the inspection log to 57.30 pounds per bushel in the vessel. This increase *was* statistically significant and is consistent with previous studies showing a slight increase in test weight where there are large increases in BCFM (see Table 2). No significant increase was found between origin and destination samples taken from the vessels, despite the settling and compaction that occurs during transit. There was a slight but not significant decrease in test weight between the vessel and the coasters.

Total kernel damage. An increase in total damage (DKT) in corn during storage or transit results primarily from mold growth. Other factors considered as DKT in U.S. grades seldom change during storage or transit. When temperatures and moisture contents are high, corn damage increases as a result of the rapid growth of microflora. No information was available on total damage in the 1985 study except for the loading log, so no comparisons could be made. In 1986 the average damage recorded at the time the barges were loaded at midwestern river elevators was 2.43 percent DKT and averaged 2.66 percent DKT when the barges were unloaded in New Orleans (see Table 2). The inspection log showed an average of 2.25 percent DKT. Composite samples taken from hold 5 in Japan averaged 2.50 percent DKT. The three composite samples from the Japanese coasters averaged only 2.10 percent DKT (see Table 2). None of these changes was statistically significant. Although laboratory analysis revealed the growth of molds, many of the moldy kernels had not deteriorated sufficiently to be considered damaged under the official interpretation of DKT in corn (i.e., the mold penetrates through the seed coat or is evident in the germ of the kernel). The only significant increase in DKT was in the hot spots in the holds, which are discussed later in this report.

*Data on origin barges and export certificates were based on diverter type samplers and the Carter-Day dockage test. Data from the vessel and the destination barges and coasters were based on samples taken by probe and evaluated on the Gamet Shaker. Differences between the results of the diverter sampler and the 10-foot probe, and the Carter-Day dockage tester and Gamet Shaker have not been consistent over time and depend in part on grain conditions. Therefore no adjustments in values have been made in this study. Comparisons between the vessel and the coasters or barges are based on identical sampling and analysis.

Changes in Nongrade Factors

Moisture. In September 1985, FGIS removed moisture as a grade factor for corn, leaving moisture content to be stipulated in the contract. The contracts specified 15.0 percent moisture for both shipments. The loading log showed 14.91 percent moisture in 1985 and 14.96 percent moisture in 1986, as determined by the Motomco meter. Samples from inbound barges in 1986 had a moisture content of 14.99 percent at the time of unloading in New Orleans using the Motomco meter. During loading of the vessel, bins were selected that allowed the elevator to meet the 15.0 percent contract. In 1986 the first three points in the market channel where moisture was measured by the Motomco meter showed no significant differences in average moisture content. There was no evidence of any pattern of moisture changes during transit or handling in either shipment. In 1986 the statistically significant difference between the moisture recorded on the certificate and the vessel samples was attributed to the difference between using the air oven and the Motomco meter. The lack of a consistent pattern of change suggests that the differences do not reflect actual changes in moisture.

Changes in moisture are more accurately determined by comparing samples tested by identical measurement technology. The moisture content of each sample sent to AEGQL was measured by the 72-hour air-oven method (see Table 3). The results indicated no significant change in moisture at any point in either shipment except from the elevator belt to the vessel in 1986. This difference is attributed to sampling variability, because the vessel samples were taken within an hour of sampling from the belt, providing little possibility of actual loss of moisture.

Particle size. The impacts kernels received during loading of the vessel and unloading with pneumatic equipment caused an increase in the percentage of smaller-sized particles at each point in the market channel. The breakage increase between the samples taken from the belt and from the ocean vessel was greater in 1986 than in 1985. Several factors contributed to the increased breakage and are discussed in subsequent sections.

In both shipments there were statistically significant increases in all sieves below, and statistically significant decreases in all sieves above, the $^{12}/_{64}$-inch sieve as a result of impacts during loading the vessel (see Table 4). The percentage of the sample retained on the $^{12}/_{64}$-inch sieve remained nearly constant, as whole kernels were broken into particles small enough to pass through the $^{20}/_{64}$-inch and $^{16}/_{64}$-inch sieves and the material previously held on the $^{12}/_{64}$-inch sieve was broken into smaller particles and held by the sieves below. The largest percentage increases were in the smallest particle-size categories. The increase in the material held on the pan (primarily dust) increased by a multiple of 3 or 4 between the belt samples and the vessel samples.

There were fewer significant changes in particle sizes between the vessel and the barges or coasters, partly because of the small number of samples taken after unloading. However, the pattern of change remained consistent, with decreases in the percentage of larger particles and increases in the percentage of smaller particles (see Table 4). After the unloading in Japan, 1985 barge samples averaged 1.44 percent and 1986 coaster samples averaged 2.62 percent of the sample passing through a $^{3}/_{64}$-inch sieve. In 1985, the percentage of corn above the $^{16}/_{64}$-inch sieve decreased from 86.82 (17.06 + 69.76 in Table 4) in the official file samples from the outbound belt to 81.19 percent in the Japanese barge samples. The change was more dramatic in 1986, decreasing from 87.95 percent in the belt samples to 78.92 percent in the coaster samples. The reduction in the percentage of larger-sized particles and the increase in fine particles and dust were dramatic and had a profound effect on the appearance of the corn.

Percentage of whole kernels. There was no significant change in the percentage of whole kernels in the 1985 shipment between the belt in the export elevator and the barges in Japan, despite the impact that occurred during loading

(see Table 4). In the 1986 shipment, however, the percentage of whole kernels dropped from 80.9 to 76.3 percent between the origin barges and the outbound belt and from 76.3 to 71.8 percent between the outbound belt and the ocean vessel. The Japanese coaster samples had only 70.7 percent whole kernels (see Table 4). This decrease between the belt and the ocean vessel was statistically significant, and further reduction occurred with each handling from the barges at the export elevator to the coasters in Japan.

Breakage susceptibility. Breakage of corn during handling is influenced by several factors, including internal stress cracks, kernel hardness, moisture, and temperature. The Wisconsin Breakage Tester (WBT) provides an indication of the susceptibility of the corn to break on impact. The breakage susceptibility of corn is affected primarily by drying temperatures and, to some extent, by genetics. Handling through the market channel increases breakage but should have a minimal effect on breakage susceptibility.

Samples from the outbound belt in the 1985 shipment tested 17.40 percent on the WBT (see Table 5). This decreased to 15.80 percent in the vessel (not significant at P = .99). Samples from the 1986 shipment showed an increase in breakage susceptibility as the corn progressed through the sequence of handling and impact, but the only statistically significant change occurred during unloading in Japan.

The intrinsic breakage susceptibility of the corn shipments was slightly higher in the 1986 shipment than in the 1985 shipment because of lower moisture content and temperatures and a higher percentage of stress cracks in 1986. The file samples taken by FGIS before loading the vessel provide the best basis for comparison. When samples were adjusted to similar moisture contents and temperatures in the laboratory, the samples from the 1985 shipment averaged 17.40 percent breakage susceptibility compared with 17.06 percent in the 1986 shipment. After loading, however, samples from the 1986 shipment showed a higher level of breakage susceptibility and percentage of kernels with stress cracks than the 1985 shipment (see Table 5). Differences between the two shipments appeared to be caused by temperature differences at loading and by the higher percentage of stress-cracked kernels in 1986.

Stress cracks. There were no significant changes in the percentage of kernels showing stress cracks in either shipment. In 1985, the percentage of kernels with stress cracks ranged from 48 to 54 percent. In 1986, the percentage of stress cracks ranged from 62 to 67 percent (see Table 5). Fractured kernels (those with one or more visible stress cracks) often shattered upon impact, accounting for both the increase in broken corn and the decrease in the percentage of whole kernels. The same impacts probably caused new stress cracks in other kernels. There was a large sampling variance in both sets of data, resulting in the conclusion that the percentage of kernels with one or more stress cracks did not change significantly during loading and unloading.

Analysis for insects. The research team evaluated only the 1986 shipment for insects. Neither the research team nor the official Japanese inspectors found any live insects in the samples collected at New Orleans or at the port in Kashima, Japan. No insects were present in the traps when they were examined before unloading. Japanese inspectors reported no insects in the 1985 shipment.

It is important to recognize, however, that the temperature and season of year influence insect infestation. Both shipments were loaded in early spring when the corn was cool enough to prevent insect activity and development in domestic storage and handling. Shipments loaded from storage facilities in summer months often are infested before loading, and higher grain temperatures at that time would encourage the development of insects during the 4- to 5-week transport period.

Mycological Analysis of Samples

A detailed analysis of the growth of mold and fungi in the vessel during transit was conducted only in 1986.

The percentage of kernels showing fungal infection was calculated for samples selected from three holds at origin and destination to determine if fungal growth occurred during transit. Fifty kernels were selected from each of the 16 probe samples taken from each layer of the holds tested. After plating, the percent of infected kernels in each layer was calculated. Five layers tested at origin provided 15 samples; four layers at destination provided 10 samples. These samples were considered to be representative of the entire vessel for purposes of comparing changes between origin and destination.

The *Student-t* test using a pooled variance with an unequal number of observations was used to determine if levels of infection increased significantly between origin and destination. The average percent of kernels infected with *Fusarium, Aspergillus glaucus,* and *Penicillium* all increased between origin and destination (Table 6). The increases in *Fusarium* and *Penicillium* were statistically significant (P = .95); the increase in *A. glaucus* was not significant. Percent of kernels infected with *A. flavus* decreased from 1.84 to 1.12 percent (not statistically significant from zero). The temperatures and moisture levels in the grain mass during transit were favorable to the growth of *Fusarium* and *Penicillium;* they were outside the optimum ranges for *A. flavus* and *A. wentii* (see Appendix A). *A. wentii* showed a significant decrease in percent of infected kernels; however, original infection rate was low and analysis at destination showed no *A. wentii* present (Table 6).

Other fungi isolated included *Alternaria* spp., *Piplodia* spp., *Cephalosporium* spp., yeasts, *Rhizopus* spp., *Mucor* spp., *Aspergillus niger, A. fumigatus,* and *A. candidus.* There were no significant differences in infection by these fungi, either singly or together, at loading or after shipment.

Samples from hot spots were supplemented with one or two samples taken a few feet away to identify the pattern of heating around the infection's focal point. An analysis of samples from these areas of heating grain showed high levels of *A. glaucus,* total *Aspergillus* spp., and *Penicillium* infection. These hot spots were in general more severely infected than samples from other areas of the hold, although a direct comparison was not possible because of differences in sampling procedures. In general, the percentage of kernels infected with *Penicillium* increased from the 1-foot level to the 2-foot level but decreased at greater depths. The reverse was true for total *Aspergillus*—apparently a response to a general decrease in temperature and moisture at increasing depths in the hot spots. It appears that the mold growth started near the surface and spread to greater depths as heat and moisture increased with respiration of the molds.

While *A. glaucus* and *Penicillium* spp. infection levels increased during shipment, it appears that cool temperatures suppressed mold development. Grain temperatures were below the optimum levels for all fungi except *Penicillium* spp. However, as evidenced by the hot spot temperatures and the increase in temperature in hold 5 at the 3-foot level, mold activity did occur and with time would have accelerated as temperatures increased. (See grain storage mold and ecology data in Appendix A.)

Segregation and Variability

Segregation during loading and unloading creates problems when a hold is divided among multiple buyers. One buyer may receive a sublot significantly different from the average quality of the corn in the vessel. Both cargoes of the *Century Progress* were distributed among many feed manufacturers and starch processors via several alternative market channels. Segregation is inevitable, but problems are usually limited to moisture and BCFM.

BCFM. The range in BCFM would be expected to increase during loading because of the segregation of fine materials, forming "spout lines,"* and as a result of an increase in the total

* Spout line is a term familiar to the grain industry—it refers to a cone or column of fine materials and small particles that develops directly below the loading spout in bins or vessels.

BCFM in the shipment. BCFM in sublot samples in the 1985 shipment varied from a low of 2.19 percent to a high of 4.36 percent as determined by the AEGQL* (see Table 7). Two-probe samples from the vessel ranged from a low of 1.97 percent (hold 5, destination) to a high of 11.11 percent (hold 2, destination). Probe samples have been found to result in slightly higher BCFM than the diverter sampler on the average, and the method of sampling in random locations generates a wider range of values than the diverter sampler, which selects kernels from throughout the 60,000-bushel (1,524 mt) sublot. Even so, the probe samples indicated segregation does occur during loading. Single-probe samples (layer 3, hold 2 at destination) exhibited an even greater range—from 1.85 to 15.29 percent. Single-probe samples from the barges after they were loaded from the vessel at destination showed a reduced range of BCFM—a low of 3.92 percent and a high of 10.78 percent. Pneumatic unloaders drawing from more than one location simultaneously tended to reblend some of the natural segregation that occurred during loading.

Another measure of variability and segregation is the variance, calculated as the sum of the squared deviation of each value from the mean of all observations in that set, divided by the number of observations, less one degree of freedom (n – 1). The comparison of the variances calculated from data from the loading log, the ocean vessel, and the barges showed an increase in variance during loading of the vessel at the origin; a decrease during loading of the barges at the destination. The standard deviation (square root of the variance) for samples from the outbound belt was 0.63; from hold 5 of the vessel at origin, 0.91; from hold 5 of the vessel at destination, 2.68; and from barges at destination, 1.81 (see Table 7). When data from all the holds and samples were combined, the standard deviations for the belt, origin vessel, destination vessel, and barges were 0.63, 1.09, 2.68, and 1.81, respectively. (These values are not shown in Table 7.) The F-test, comparing variances, showed a statistically significant increase in variance between the belt and the vessel. But when single-probe samples were removed from the analysis, the hypothesis of equal variances between origin and destination samples from the vessel could not be rejected.

In the 1986 shipment, segregation and variability could be identified starting with average values for barges as they were being unloaded. Average BCFM for each incoming barge (holding approximately 55,000 bushels [1,397 mt]) ranged from 1.23 to 4.01 percent—a 2.78 percentage point spread (see Table 8). Blending by the exporter lowered the range to only 1.1 percentage points between highest and lowest sublots (approximately 60,000 bushels, not shown in Table 8). However, component samples representing 30,000 bushels showed a higher variation with a standard deviation of 1.01, compared with 0.61 in the barges. The hypothesis of equal variance was rejected at the 99 percent level (see Table 8).

Segregation increased dramatically during loading of the vessel. Each sample taken in the hold represented approximately 4,300 bushels (109 mt). Two-probe samples taken from hold 5 during loading had a minimum value of 3.76 percent BCFM and a maximum value of 13.72 percent BCFM, giving a range of 9.96 percentage points. The single-probe samples taken in hold 1 (each probe representing 1,700 bushels [43 mt]) had a range of 11.61 percentage points, from a low of 2.60 percent to a high of 14.21 percent (see Table 8). Comparison of the variances using only two-probe samples shows a statistically significant increase in segregation between the belt samples and the vessel.

Loading spouts were moved frequently during loading to facilitate uniform sampling by layer. As a result, the "spout line" effect was probably less than under normal loading conditions. However, the samples taken from the perimeter quadrants in hold 1 averaged 1.4 percentage points lower in BCFM than those from the inside quadrants—a statistically significant difference (see Figure 5). This would tend to

* AEGQL procedures resulted in slightly higher levels of BCFM than were reported by FGIS.

support the belief that most of the smaller particles stayed in the spout lines, and the larger particles (whole kernels and large broken pieces) tended to flow to the outside.

There is no basis for expecting any change in segregation during transit. Previous studies have shown no evidence of fines shifting in a stationary grain mass. This conclusion was reinforced by data from hold 5 obtained during the unloading in Japan. The two-probe samples had a range in BCFM of 9.71 percentage points, from 4.14 to 13.85 percent, compared with origin data with a range of 9.96 percentage points. Standard deviations at origin and destination were 2.08 and 1.90, respectively—not significantly different.

Changes in BCFM in top and bottom layers during transit were also analyzed to determine any shifts (see Table 10). Although there were positive and negative changes in average sample values, these differences are attributed to sampling variance. The average of all seven layers tested changed by only 0.1 percentage point, and there is no evidence that broken corn and foreign material or fines moved among layers during transit.

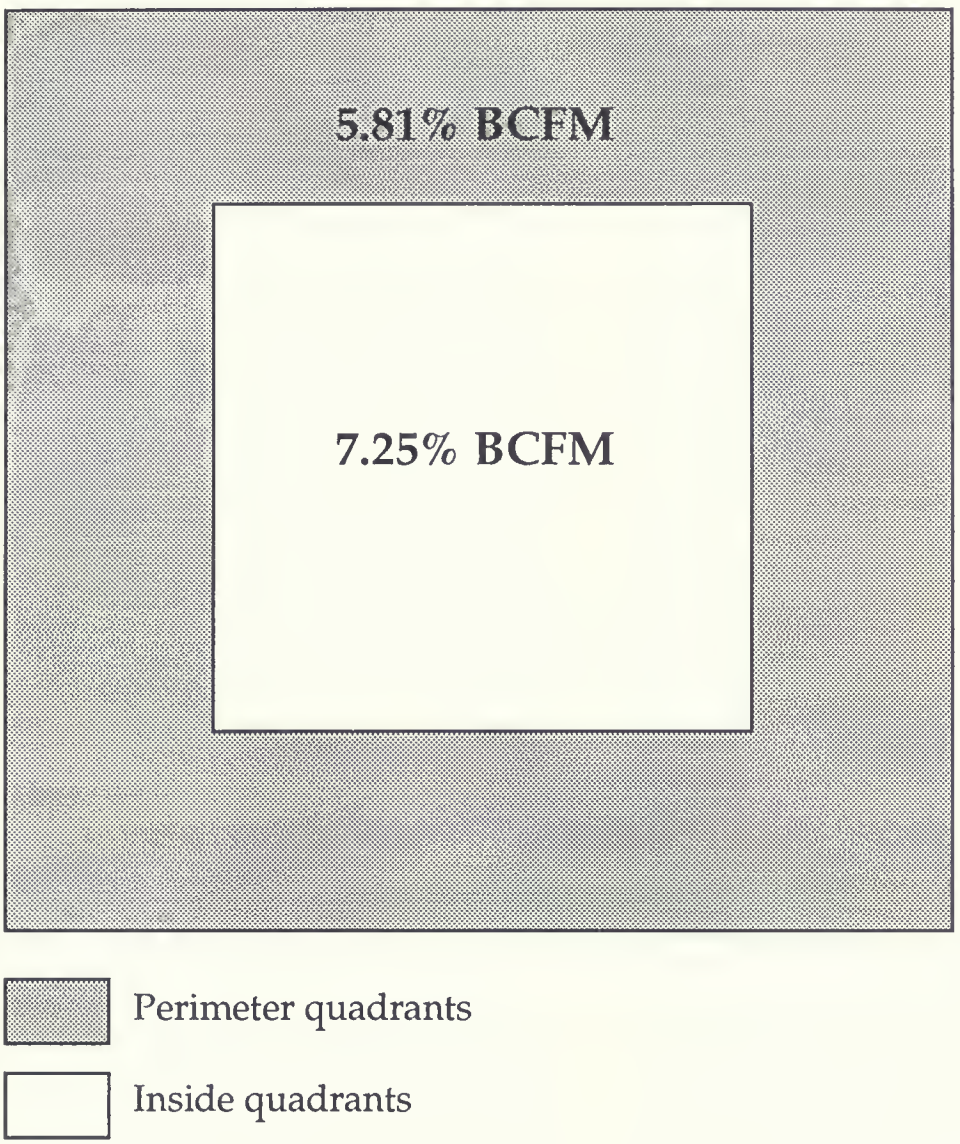
Segregation persisted after unloading in the 1986 shipment. The largest range in BCFM among single-probe samples on any single Japanese coaster was 11.23 percentage points, from a low of 4.89 percent to a high of 16.13 percent (see Table 8). The range was only slightly less than the range of 11.61 percentage points among single-probe samples taken from hold 1. A second coaster had a range of only 5.7 percentage points between high and low readings of BCFM. These data indicate that segregation within a coaster sublot remains after unloading the vessel but varies among barges or coasters depending on the procedures followed during discharge of the cargo. The range among coasters in average BCFM was only 1.95 percent, indicating a dramatic reduction in variation when dealing with sublots as large as a full coaster. The blending that occurs when several pneumatic unloaders are unloading simultaneously from more than one hold also reduces segregation among barges and coasters. The difference between sample variance in the vessel and the coasters was not statistically significant.

Percentage of damaged kernels. In the 1985 study, information on damage (DKT) was available only from the loading log data. For that reason, no analysis of variability was attempted. In the 1986 shipment, DKT was systematically evaluated on a large number of samples at each point in the market channel. Incoming river barges had a range of 7.0 percentage points from 0.5 to 7.5 percent DKT as determined by the export elevator. The 60,000-bushel (1,524 mt) sublots on the export certificate had a range of only 2.1 percentage points between the highest and lowest sublot. The contents of several barges were blended during loading, decreasing the range. A wider variance appeared in the twenty composite samples from hold 5 in Japan, ranging from 1.5 to 4.1 percent DKT. However, these samples were taken by probe and represented a smaller volume. The three composite samples from the Japanese coasters had a lower range (from 1.8 to 2.4 percent) possibly because of the blending of several holds during the loading of one coaster, the larger volume represented by a coaster, the small number of coasters sampled, and the compositing of 12 probes per coaster sample.

Moisture. In the 1985 shipment, the moisture content of individual sublot samples obtained from the outbound belt ranged from 14.40 to 15.00 percent with a standard deviation of 0.15 (see Table 9). The moisture content of the probe samples taken from the vessel at the origin and destination ranged from 14.20 to 15.30 percent with a standard deviation of 0.20—nearly identical to that of the sublots. Samples from all barges loaded from the vessel in Japan ranged from 14.10 to 15.00 percent moisture in single probes. The average for each barge had an even smaller range in moisture (14.52 to 14.72 percent) and a standard deviation of 0.12.

In the 1986 shipment, the average moisture determined on each incoming barge at the New Orleans export elevator ranged from 12.9 to 15.5 percent (see Table 9). Moisture content of

Figure 5. Comparison of percentage BCFM in the perimeter and inside sectors (average of layers 1- 4, hold 1, New Orleans, 1986).



the component samples from the belt taken during loading varied from 13.30 to 15.40 percent. The range in moisture found among incoming barges at the export elevator was reduced during loading of the vessel through the loading strategy of the elevator. Grain was drawn from several bins simultaneously to achieve the moisture level dictated by the contract. Samples taken from the vessel at the origin and destination showed a range in moisture of 2.60 percentage points, from a low of 12.80 percent to a high of 15.40 percent. (This range included single-probe samples taken from hold 1.) The standard deviation was 0.36. The 36 samples taken from the three Japanese coasters had a range of only 0.60 percentage points (see Table 9). The average moisture content of each of the three coasters showed much less variability: a range of 0.20 and a standard deviation of 0.11. These results indicate that there is very little segregation of moisture within the hold or during unloading. The samples from several holds of both shipments show a uniform blend of the original inbound moisture range to achieve uniformity throughout the vessel.

There has been some concern that moisture migration within the hold of a vessel results in an increase in the moisture content in the top level of each hold. This hypothesis was tested in the 1986 shipment by comparing layers at the origin and destination for those holds and layers sampled at both points (see Table 10). There was no evidence of moisture migration. The average moisture content of the top two layers (layers 4 and 5) of holds 5 and 3 was 14.22 percent at origin and 14.22 percent at destination (see Table 10). The moisture content of the top layer of hold 3 increased 0.12 percentage points between New Orleans and Japan. The top layer of hold 5 decreased 0.05 percentage points in moisture content. The two bottom layers (layers 1 and 2) of hold 5 increased in average moisture by 0.20 percentage points between New Orleans and Japan. The bottom layers of hold 3 were not sampled in Japan.

Additional analysis of possible moisture migration was conducted by sampling in one-foot layers to a depth of 6 feet in holds 5 and 7. There was no consistent pattern of either increasing or decreasing moisture regardless of depth (see Table 11). Thirteen sectors showed a slight increase in moisture, while 19 sectors showed a decrease in moisture from the 1-foot to the 6-foot level (see Table 11). Average moisture over all sectors was higher on the surface than at the 6-foot level, but only by 0.04 of a percentage point.

The moisture contents of these samples were validated by having JGIA test a split sample within 10 days after the sample was collected. Their results were compared with the analysis of the other half of each sample tested at the University of Illinois Agricultural Engineering Grain Quality Laboratory several weeks later. The average moisture determined by the USDA's air-oven method by JGIA averaged 0.09 percentage points higher than that determined by the University of Illinois using the same oven procedure (see Table 11), which is well within the accuracy of the method.

Individual kernel moisture. The moisture in a sample of grain, whether determined by a dielectric moisture meter or by an oven test, is based on the average of all the kernels in that sample. Although the average moisture may indicate that the grain is safe for storage or transport, the sample may contain a range of moisture contents that provide conditions conducive to rapid deterioration. Blends of diverse moisture levels will still meet contract specifications based on average moisture, even though individual kernels may significantly exceed the range for safe storage and transport. The range of moisture within a sample was estimated by determining the moisture content of individual kernels selected randomly from several locations throughout the market channel.

In the 1985 shipment, five samples (125 g) were selected randomly from the diverter sampler on the outbound belt at the export elevator. From each sample, 48 kernels were selected and their moisture content determined in the air oven. Similar samples were taken from five sample bags taken from the vessel in Japan. The

moisture content of individual kernels obtained from both locations followed a similar distribution pattern.

The results of the analyses of the origin samples show a range of five percentage points of moisture among individual kernels. The accuracy of the individual kernel measurement is indicated by the average moisture content of 15.1 percent, based on individual kernels, compared with the average moisture content of 14.8 percent, reported for the 15,000 bushel (381 mt) components from which the samples were drawn (see Table 12). The 14.8 percent moisture content was determined by FGIS at New Orleans using the Motomco meter.

The data on individual kernel moisture indicated that a range of moisture existed within the sublot of corn (see Figure 6). The moisture content of individual kernels in origin samples ranged from 12.9 to 17.4 percent in sample 3, with more than 87 percent of the kernels falling within $\pm$ 1 percentage point of the mean. A similar pattern was evident in all four samples. Sample 3 had a distribution similar to a bell-shaped normal curve centered on 15.0 percent. Sample 4 was skewed to the left, with 42 percent of the kernels falling below 15.0 percent moisture. Sample 1 in Figure 6 shows a sample centered (modal value) at 16.0 percent moisture with a relatively narrow distribution. Most of the kernels from this sample were within 0.5 percent of the modal moisture of 16.0 percent. Sample 2 in Figure 6 had a relatively flat distribution and exhibited a tendency toward a bimodal distribution, with one peak at 14.5 percent and one at 15.5 percent.

No bin in the export house contained corn with average moisture content as high as 17.0 percent or as low as 13.0 percent. This suggests that the moisture range in the samples was present before loading the grain into the export house. Although only 1.7 percent of the kernels contained 17 percent or higher moisture, the presence of these high-moisture kernels indicates the lack of complete equilibration during the time the corn was in transit or was in storage bins in the elevator. An example helps put this 1.7 percent in perspective. In a 2,000,000-bushel (50,800 mt) shipment, the results of this limited sample indicate there would be 34,000 bushels (863 mt) of corn at 17 percent moisture or higher. This is not a stable situation in a static grain mass held for three to five weeks in the hold of the vessel. Storability studies have shown that deterioration will occur in 18 percent moisture corn in as little as 4 weeks after the corn has reached 80° F [10].

The results from destination samples showed the same variability in moisture as that found in the origin samples (see Table 12 and Figure 7). The average of the individual kernel moisture at the origin was slightly higher than the average at the destination (15.1 versus 14.9 percent). However, the range among kernels within the five samples was greater at destination (5.12 percent at origin and 5.72 percent at destination—see Table 12). The standard deviation was slightly smaller among the kernels in the destination samples (see Table 12). This would indicate that the moisture migration was minimal within the mass, even though the time between testing was approximately 10 weeks. The moisture content at destination varied from a low of 12.0 percent in sample number 2 to a high of 17.7 percent in sample number 5.

The accuracy of the single-kernel moisture is again validated by comparing the average moisture content of the bulk sample with the average moisture of the 48 individual kernels. The overall average for the five samples taken at destination was 14.1 percent in the University of Illinois bulk sample and 14.9 percent for the individual kernel moisture using the air–oven method for all determinations (see Table 12).

The range in moisture content among kernels from all five samples at origin was 12.6 to 17.7 percent (see Table 12). The total range among individual kernels was essentially unchanged (12.0 to 17.1 percent) among kernels taken from five destination samples. However, the distribution of individual kernels over the range of moisture shows a generally narrower distribution curve in the destination samples (see Figure 7). The distribution is centered on a generally lower mode in the destination

Figure 6. Frequency distribution of individual kernel moisture in origin samples, New Orleans, 1985.

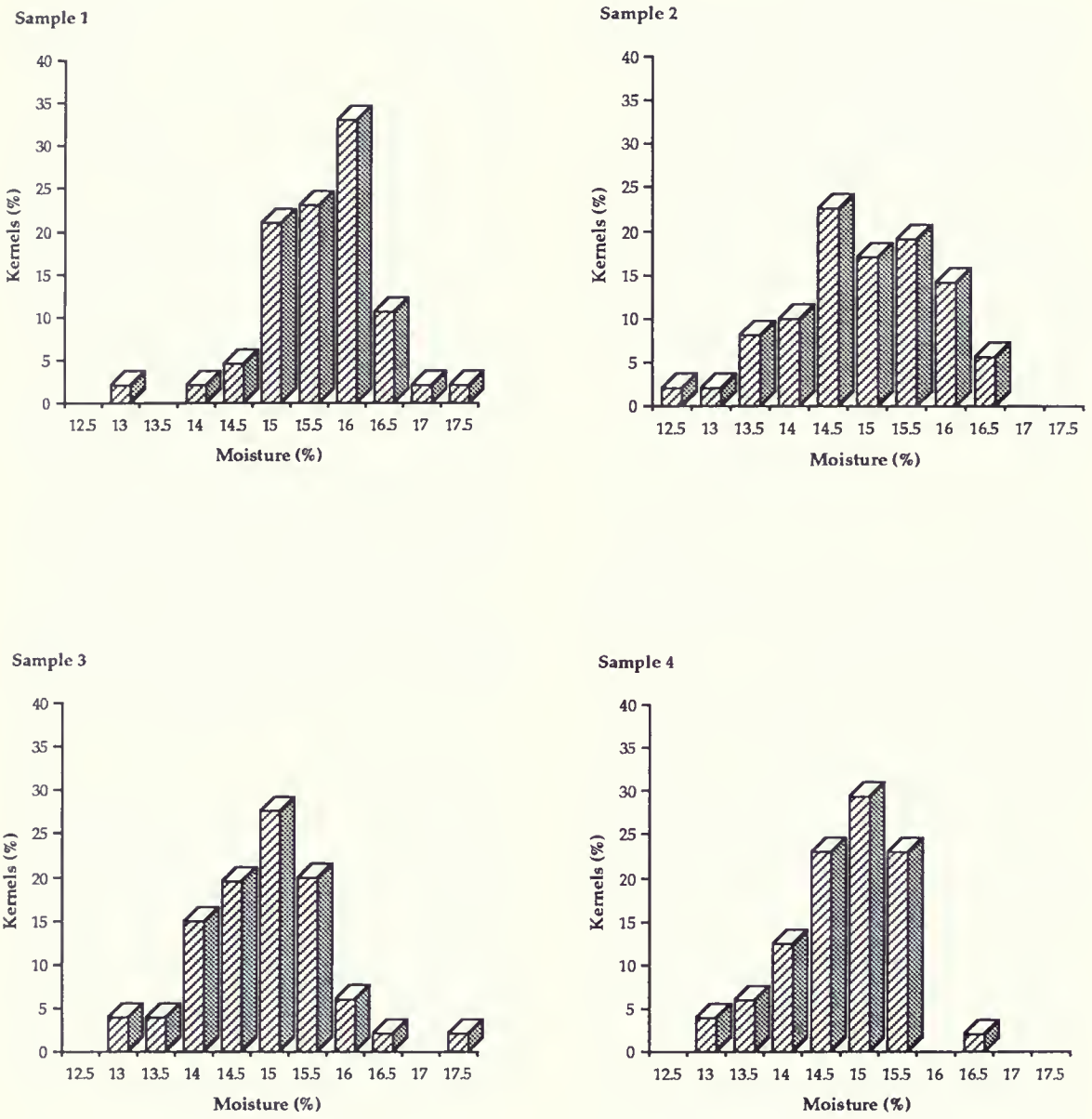
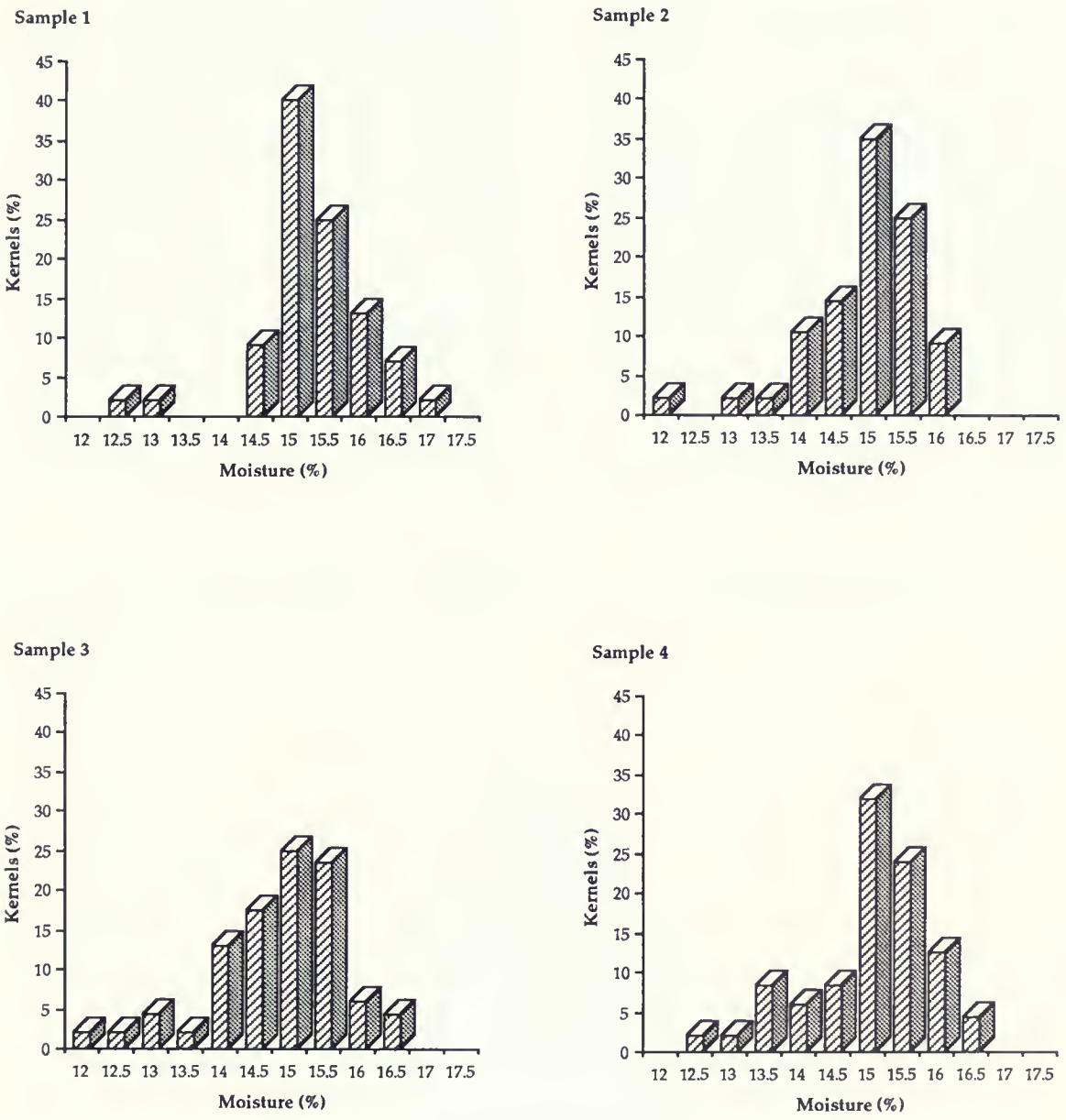


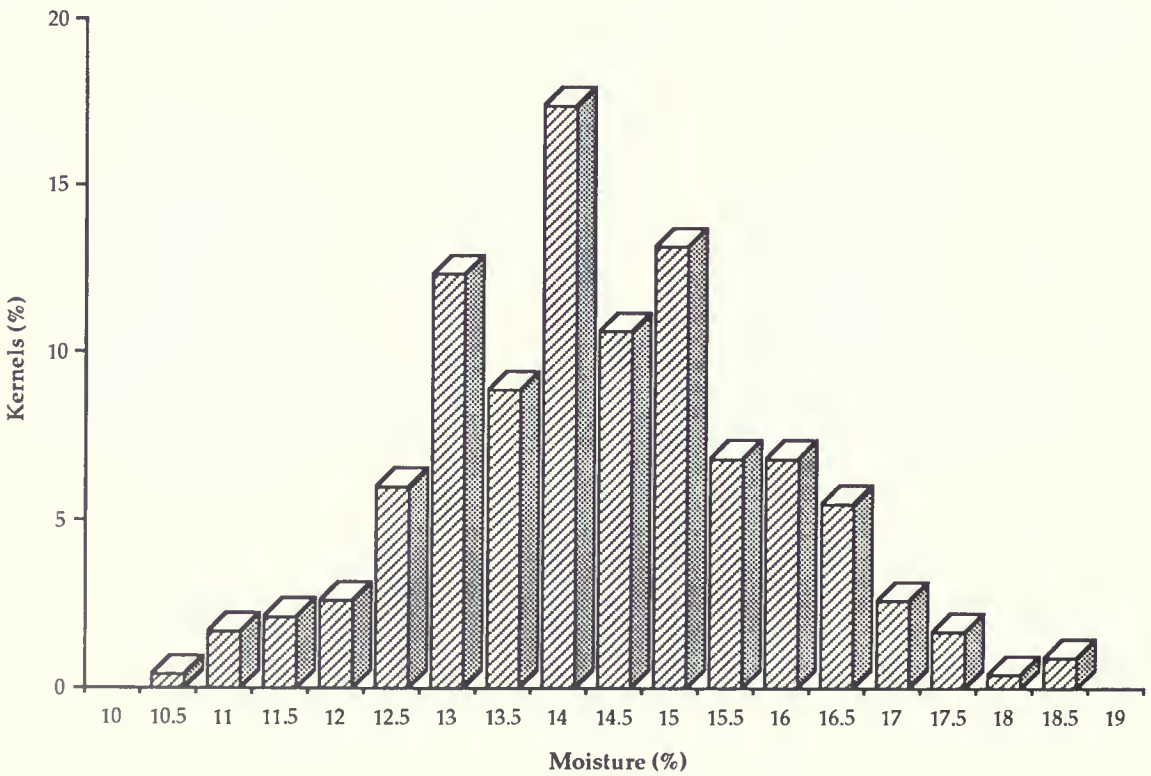
Figure 7. Frequency distribution of individual kernel moisture in vessel samples, Japan, 1985.



samples. The higher percentage of samples in the modal (most frequent) moisture bracket (i.e., 15.0 percent in samples 1, 2, 3, and 4) indicates that the kernels with the highest moisture content gave up moisture during transport.

In the 1986 shipment, samples from barges supported the hypothesis that moisture variability among individual kernels existed before the corn arrived at the export elevator. Individual kernel moistures were determined from samples taken from the incoming barges, from the outbound belt, and from the coasters in Japan. Each kernel was individually sealed in a vial at the time it was removed from the sample. The moisture content of individual kernels taken from inbound barges at New Orleans ranged from 10.5 to 18.7 percent (see Figure 8). Nearly 25 percent of the kernels had moisture contents higher than 15 percent. Ten randomly selected samples from the outbound belt had a slightly narrower range, but more than 30 percent of the kernels had moisture contents greater than 15 percent (see Figure 9). The highest kernel moisture was 18.4 percent. These kernels were clearly unsafe for long-term storage or for transport in the closed hold of an ocean vessel. Samples taken from two of the coasters in Japan had a much narrower range of moisture, with 98 percent of the kernels being within 2 percentage points of 15 percent (see Figure 10). Fewer than 30 percent of the kernels were above 15 percent. The maximum moisture of any kernel was 16.8 percent. The narrower range can be explained by moisture equilibration during the three weeks in the vessel's hold or by the fact that only two

Figure 8. Frequency distribution of individual kernel moisture in incoming barges, New Orleans, 1986.

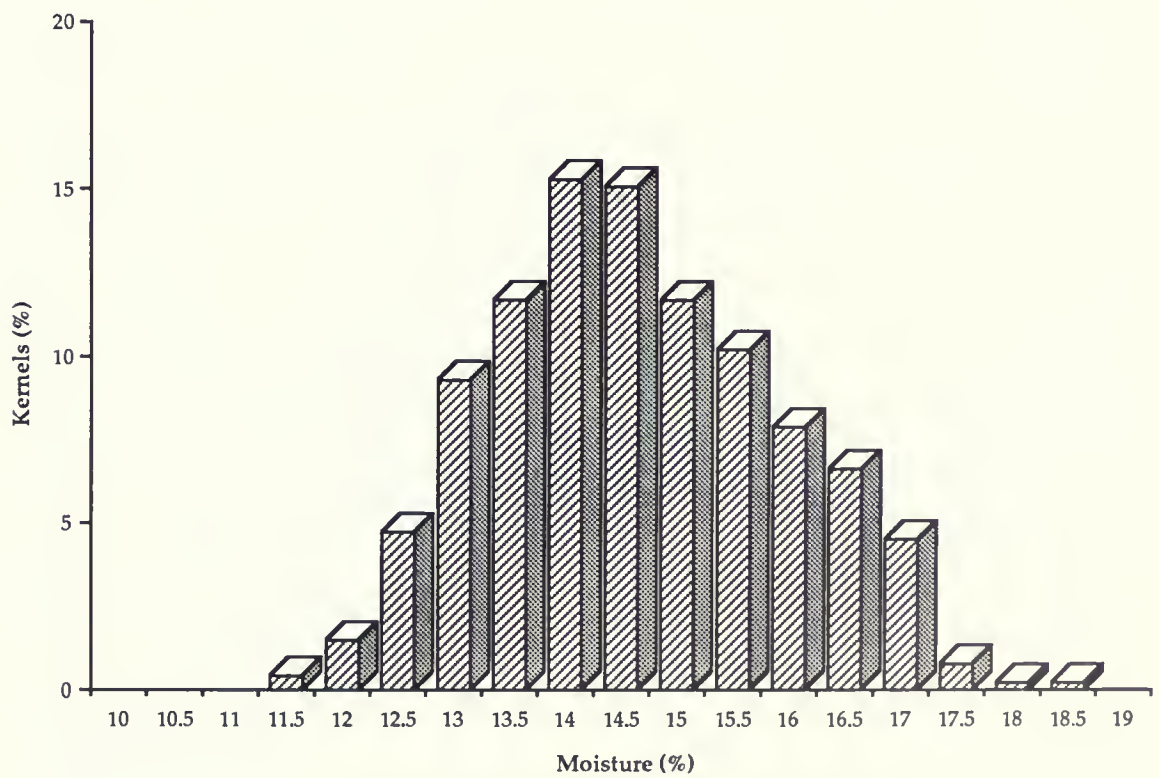


samples were analyzed from the Japanese coaster.

In each sample at the origin and destination for both shipments, the average moisture of the 48 kernels was within 0.8 percentage points of the bulk sample from which the kernels were drawn. The average of the individual kernels in all samples was within 0.8 percentage points of the bulk average. This provides confidence in the accuracy of the method used for individual kernels, even though the method is still considered experimental.

Percentage of whole kernels. The percentage of whole kernels in incoming barges in 1986 ranged from an average of 70.60 percent in one barge to 89.00 percent in another. The standard deviation was 4.57 (see Table 13). The standard deviation decreased slightly in the samples taken from the belt as a result of drawing grain from several bins. Samples from the outbound belt taken in 1985 and 1986 had a similar range in the percentage of whole kernels, although the average was slightly higher in the 1986 shipment. In both shipments, variation in the vessel samples was much greater than in the belt samples. This was caused in part by the difference in sampling methods between the belt and the vessel but also by the segregation during loading, where whole kernels rolled to the edges of the many spout lines created as the loading spouts were moved. The range in the percentage of whole kernels among individual samples taken from the barges at destination was greater than in the vessel in the 1985 shipment; the standard deviations were slightly higher in the barges and coasters than in the vessel in both shipments.

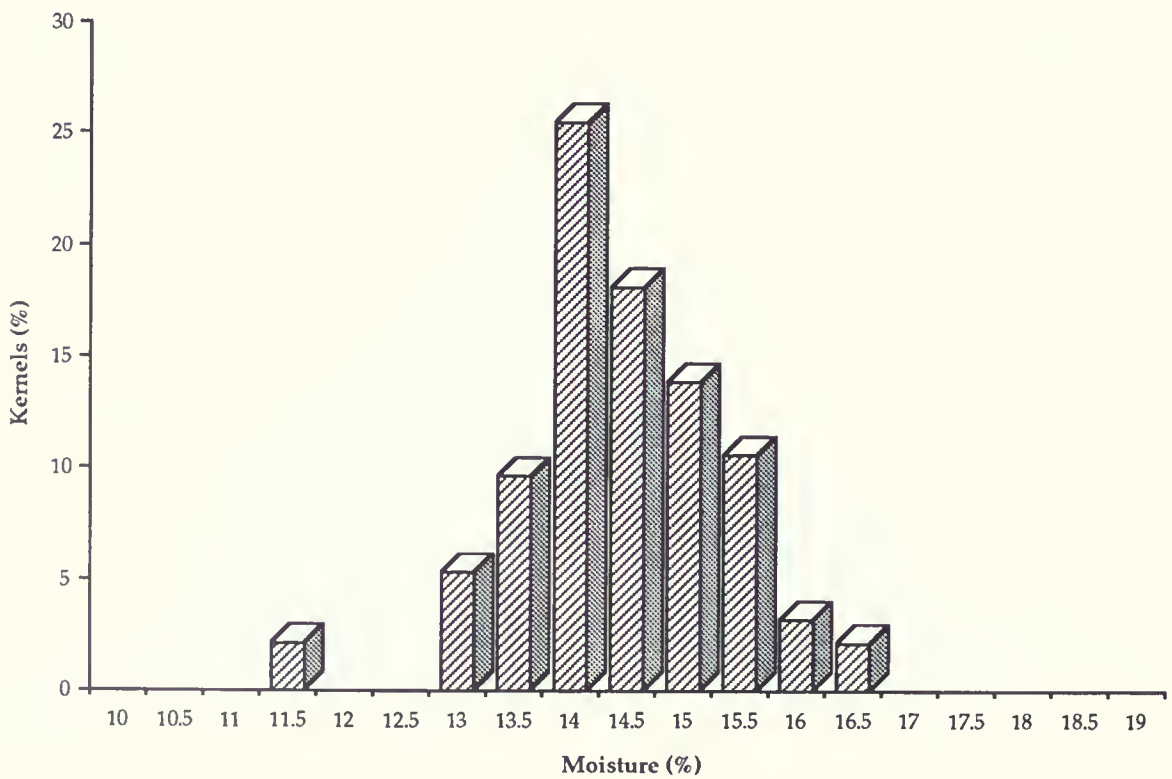
Figure 9. Frequency distribution of individual kernel moisture in sublots, New Orleans, 1986.



Stress cracks. The range and standard deviation in the percentage of stress cracks increased with each handling, as measured in samples taken from the outbound belt, the vessel, and the barges in Japan (see Table 14). The standard deviation increased from 6.62 in the belt samples to 8.70 in the two-probe samples from hold 5 of the vessel at origin to 9.66 in the barges at destination. In the 1986 shipment, the standard deviation and range in the percentage of stress cracks decreased between origin barges and destination coasters (see Table 15). The average percentage of kernels with one or more stress cracks in each inbound barge varied from 30 to 86 percent; the two-probe samples in the vessel ranged from 28 percent (hold 5) to 90 percent (hold 7). The single-probe samples showed no greater variation than the two-probe samples. Samples from the three coasters loaded from the vessel in Japan ranged from 52 to 76 percent of the kernels having one or more stress cracks; the standard deviation was only 6.33 (see Table 15).

Breakage susceptibility. The primary factors that influence breakage susceptibility in corn are the drying method and the temperature of the corn during handling. The variety of corn also affects the breakage susceptibility, as do the cylinder speed and concave adjustments of the combine. Much of the variability existing among individual barges arriving at the export elevator disappeared by the time the corn was blended for export and sampled from the outbound belt (see Table 16). The breakage susceptibility of samples from inbound barges in 1986 ranged from 9.51 to 28.02 percent, with a standard deviation of 3.72. The range and

Figure 10. Frequency distribution of individual kernel moisture in coasters, Japan, 1986.



standard deviation decreased slightly in the belt samples. Changes in the breakage susceptibility through the market channel were relatively small in both shipments. The apparent increase in standard deviation from belt to vessel in 1986 was not statistically significant. In 1985, the increase from belt to vessel in standard deviation was significant. The range and standard deviation in the 1986 shipment were much greater than the 1985 shipment. The range among barges and among holds indicated a possible explanation of differences in the total breakage at destination.

Particle size. The variability among samples in particle size increased greatly during loading and unloading in both shipments (see Tables 17 and 18). The increase was greatest in materials passing through the 8/64-inch sieve. In the 1985 shipment the standard deviation for particles less than 3/64 inch in size ("Solid pan" in Table 17) increased from 0.14 on the belt to 0.48 in the vessel to 0.73 in the barges. A similar increase was found in the next two larger sieve sizes (see Table 17). The range and standard deviation in the two largest particle sizes generally decreased through the market channel.

None of the belt samples taken by the diverter sampler in 1986 had more than 0.68 percent or less than 0.08 percent of fine dust material smaller than 3/64 inch in size (see Table 18). In contrast, the percentage of dust in samples taken from the vessel ranged from 0.19 to 3.64 percent. The single-probe samples had a wider range than the two-probe samples from any of the holds. Samples from the outside area of the hold tended to have lower levels of fine material. Samples from the Japanese coaster ranged from a high of 6.49 percent to a low of 0.67 percent of the sample passing through the 3/64-inch sieve. Each handling increased the percentage of fine materials, raising both the highest values and the lowest values and increasing the range and standard deviation.

Analysis of the larger-sized particles showed similar results. Unloading caused a decrease in range, with both high and low values decreasing. For example, samples from the belt ranged from 59.92 to 73.80 percent of particles larger than 16/64 inch. Samples of this same grain taken from the vessel after loading ranged from 55.74 to 71.74 percent remaining on top of the 16/64-inch sieve; from Japanese coasters the range was 53.31 to 65.75 percent (see Table 18).

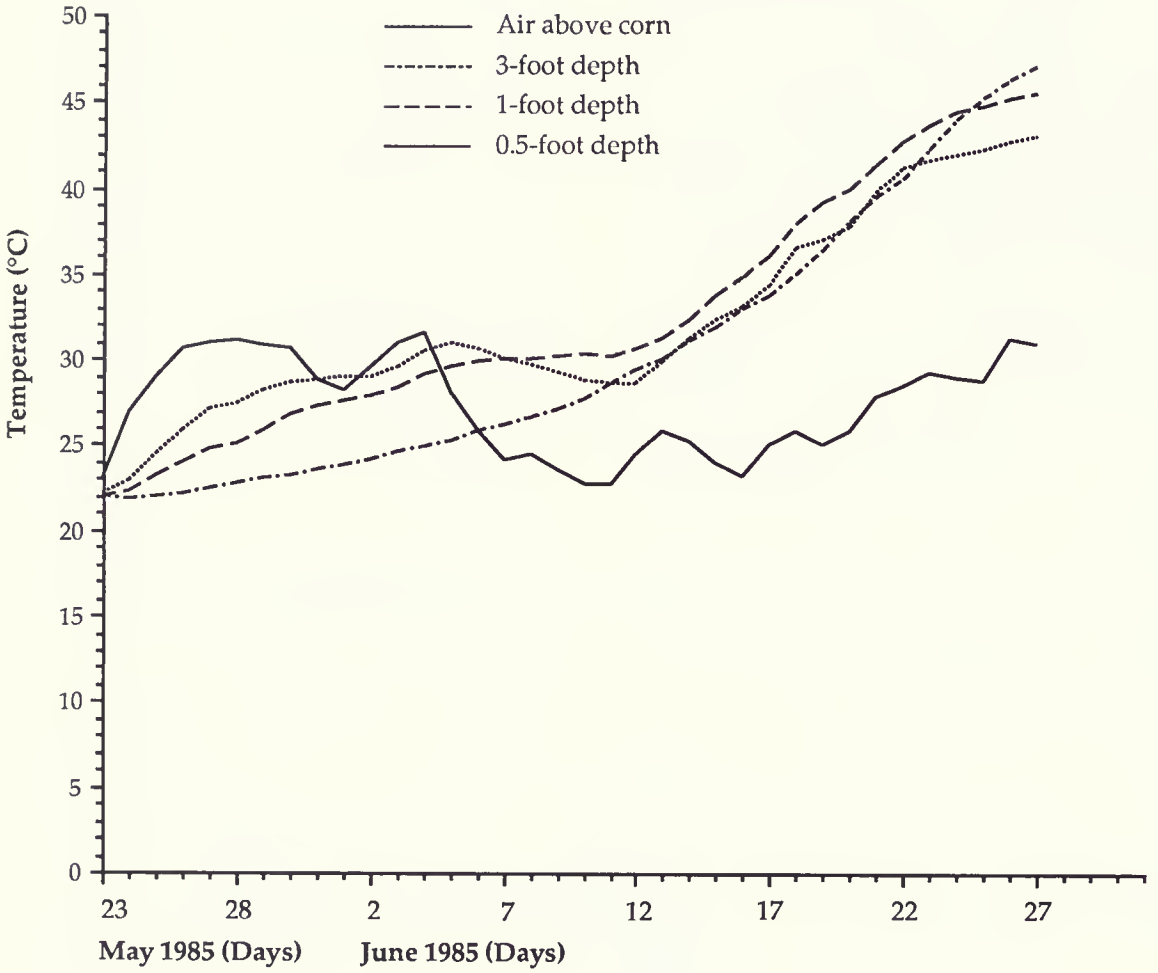
The variability in smaller particle sizes tended to increase with handling in both shipments. An increase in the percentage of broken corn and fine material was accompanied by an increase in segregation. The segregation and nonuniformity concerns of foreign buyers are justified by the variability among samples found in this shipment. Fine particles and broken kernels segregate during loading and result in wide ranges in BCFM among sublots.

Temperature Changes During Transit

Temperature sensors in hold 5 in both shipments and in hold 6 in the 1986 shipment identified a definite pattern of temperature changes and provided a partial explanation of quality deterioration during transit.

In 1985, corn temperatures in all locations were quite close to 22°C in the first reading after the vessel was loaded. The air temperature above the corn was approximately the same as the corn temperature when the vessel moved out of the berth on May 23 (see Figure 11). By May 28, air temperatures above the corn had reached 31°C. Corn temperatures at the 0.5-foot, 1-foot, and 3-foot levels followed the air temperatures upward but lagged by several days. By June 4, air temperatures had started down, reaching 22°C on June 11. But the external heat and the moisture content of the wetter kernels created conditions for microbiological heating. The temperatures at the 3-foot level continued upward, eventually surpassing those at the 1-foot and 0.5-foot levels and reaching a high of 47°C (117°F) on June 27 in Japan. The cooler air temperatures, starting June 4, cooled the corn to the 0.5-foot level and delayed the microbiological heating for nearly one week. But the internal heating eventually suppressed the effect of the cooler air temperature (see Figure 11).

Figure 11. Temperature changes within the vessel during transport from New Orleans to Japan, 1985.



Temperature patterns from the wall inward, caused by temperature changes in the sea water, demonstrate again that bulk corn is an excellent insulator. The temperature against the wall increased and decreased with changes in the temperature of the sea water (see Figure 12). Corn-temperature changes at 0.5, 1, and 3 feet in from the wall lagged by several days, but never reached levels sufficiently high to cause microbiological heating.

Corn temperatures at the time of loading were lower in 1986 than in 1985 (15°C versus 22°C). The air temperature above the corn and below the hatch was also slightly lower than the corn temperature as the vessel left New Orleans in 1986 (see Figure 13).

Corn temperatures recorded by sensors in holds 5 and 6 during the voyage in 1986 also revealed the insulating effects of corn. Air, water, and fuel tank temperatures had a definite effect on the temperatures of corn near the heat source; but as distance from the source increased, the temperature rise was less and the time lag increased. The sensors identified an air temperature of 30°C in the hold above the corn when the ship passed through the Panama Canal. Once the vessel passed through the Panama Canal, air temperatures decreased while corn temperatures 1 foot below the surface continued to rise for several days (see Figure 13), showing a delayed reaction to temperature change as the depth increased. Temperatures on the floor above the fuel tanks of hold 5 showed the same type of delayed reaction, even with the extremely high temperatures experienced during the transfer of fuel.*

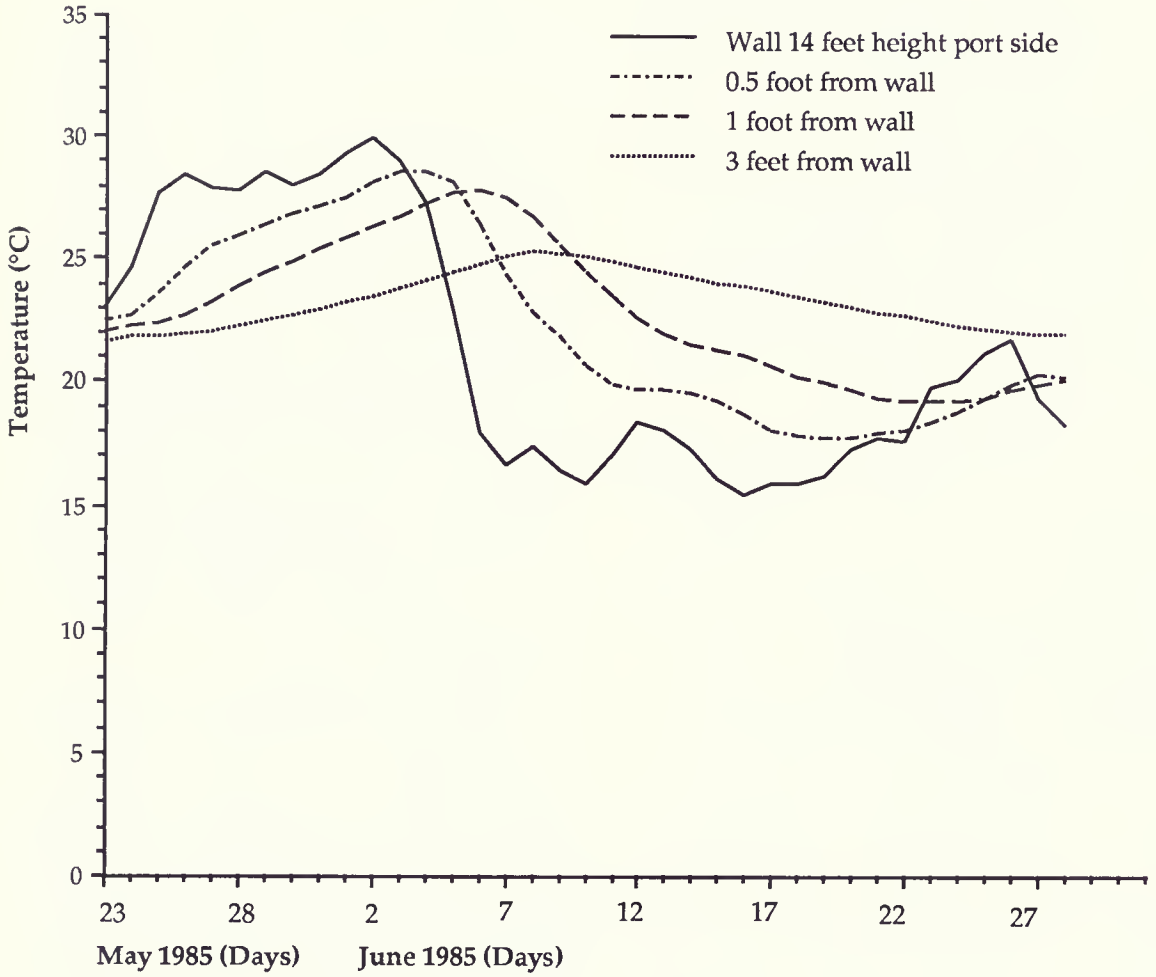
The floor temperature increased to nearly 55°C (131°F) as the fuel in the tanks was being heated March 26 to 28 (see Figure 14). Temperatures 1 foot above the floor over the fuel tank also increased with a lag of several days. Up to a distance of 1 foot from the heat source, the corn cooled as the floor surface cooled. But at 3 feet above the floor there was a slow but steady increase in temperature throughout the voyage as a result of the time required to transfer heat from the source through the corn. The rapid fluctuations in floor temperatures were reduced to a small and gradual increase as the heat dissipated through the corn mass. Corn temperatures never reached the source temperature at any location (see Figure 14).

In nearly all locations, temperatures were lower at greater depths. The only notable exception was hold 6, where the temperature was nearly constant throughout. Hold 6 was slack, having been filled to only about three-fourths of its capacity. The greater air space above the corn surface tended to insulate the corn from the high outside temperatures during transit through the Panama Canal. The daily temperature log for the sensors in holds 5 and 6 indicated that the surface temperature in the slack hold responded more quickly to changes in air temperature than the full hold did. For example, the surface temperature of both holds was above 28°C by the eighth day after the vessel left New Orleans. By day 15, the surface temperature in hold 5 cooled to 21°C, while hold 6 cooled to 17.6°C. Locations other than the surface in hold 6 showed temperature changes similar to hold 5.

Unlike the results of the 1985 study, the conditions of temperature and moisture in 1986 did not give rise to rapid biological heating throughout the hold. The necessary moisture and microflora were present in both cases, and the high temperature sources were the same (the fuel tanks and the Panama Canal climate). The difference was in the original temperature of the corn at the time of loading the vessel: 22°C in 1985, compared with 15°C in 1986. The lower temperatures of the corn in the vessel in 1986 reduced the effects of the high air temperatures in Panama, and kept the majority of the corn in the vessel below the critical point for temperature, time, and moisture required for generating microbiological heat. The presence of several hot spots in the 1986 shipment suggests that heating from biological activity started in some isolated areas and would have

* Due to the high viscosity of the fuel used in ocean vessels, the fuel must be heated above 50°C during pumping from the storage tanks. Ship masters usually recognize the potential for damage to the cargo and keep the heating period as short as possible.

Figure 12. Temperatures averaged for 24-hour periods from hold 5 located 20 feet forward of aft bulkhead wall, 1985.

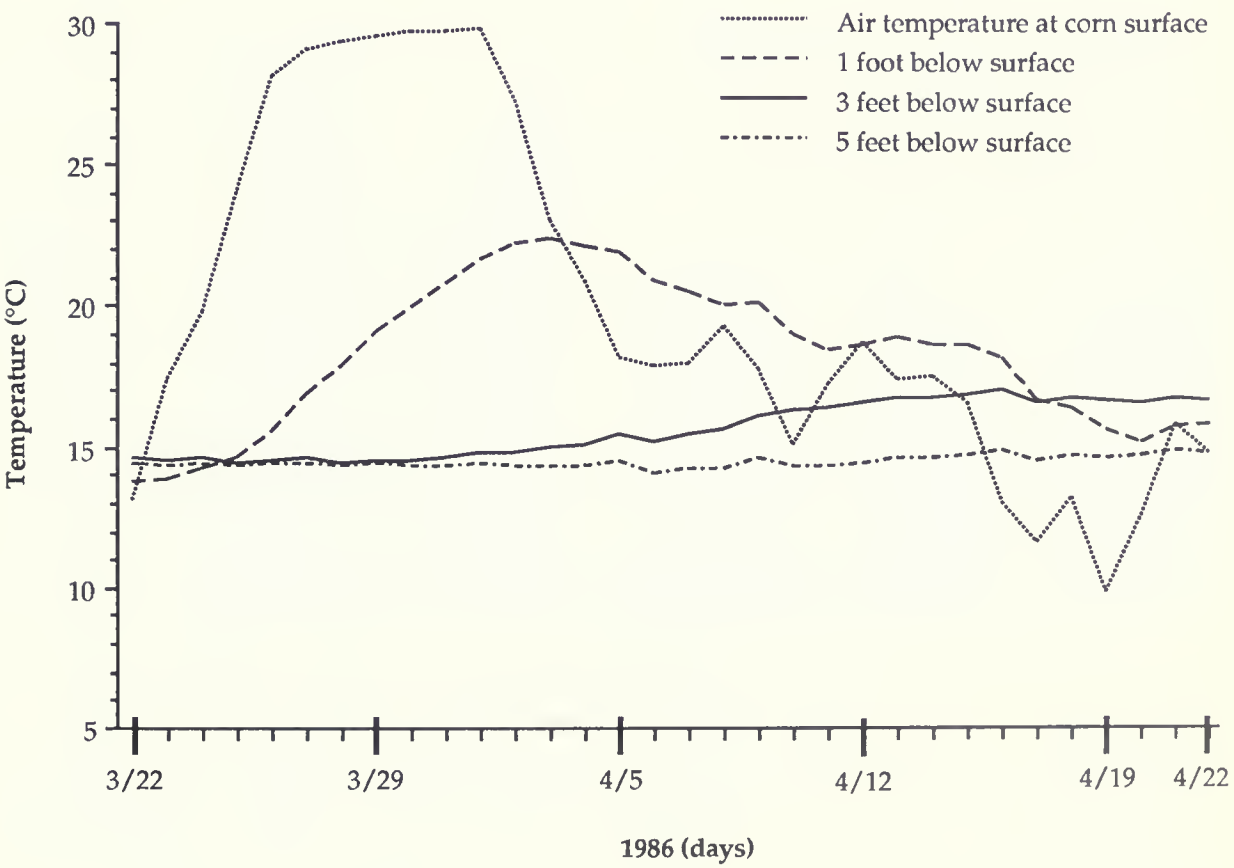


increased if more time had passed before unloading.

Temperature in the "hot spots." In addition to continuously monitoring the temperature in holds 5 and 6 during the 1986 voyage, researchers used a portable thermocouple recorder to test for temperature differences at random locations in all seven holds after the hatches were opened in Kashima. The temperature probe permitted the measurement of temperatures at vertical intervals to a depth of 5 feet in holds 1, 2, 5, 6, and 7 and a depth of 8 feet in holds 3 and 4. In addition to sampling at random locations in each hold to develop a vertical profile, hot spots of 20°C or above were selected for a detailed probe-sampling conducted in and around each hot spot. The temperature profile outside the hot spots showed a uniform temperature gradient decreasing at greater depths (see Figure 15). The temperature at the 5-foot and 6-foot levels approached the temperature of the corn recorded when the vessel was loaded (15°C in Table 19). Nonuniformity was evident in many instances. The insulating effect of the corn maintained temperatures below the 6-foot depth very close to the original temperature despite the effects of the sun on the air space below the hatch covers and on the top 1 foot of grain.

The relationships among moisture, temperature, and mold growth are demonstrated in an analysis of selected hot spots in holds 1 and 3 (see Figure 16 and Table 20). Location 3F (see Figure 16) had a surface temperature of 38°C

Figure 13. Average daily temperatures (°C) measured near the surface during shipment from New Orleans to Japan, 1986.

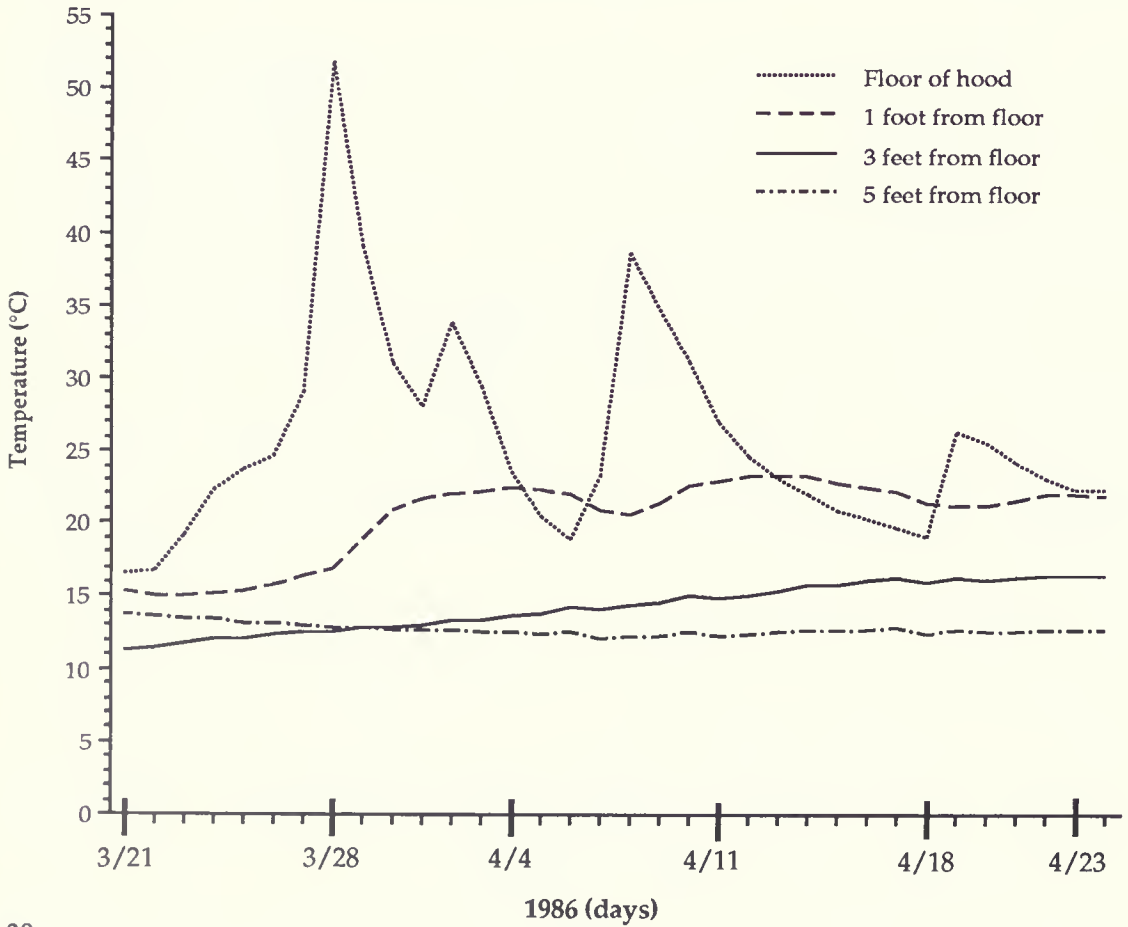


(100°F) decreasing to 21°C at the 2-foot level; 12°C at the 4-foot level, and 10°C at the 6-foot level. Samples at each 2-foot increment were analyzed for moisture, damage, and mold infestation (see Table 20). The moisture content at the surface for location 3F was 18.1 percent, decreasing to 15.3 percent at the 3-foot level. Damage at the surface was 29.2 percent, declining to 1.0 percent at the 5-foot level. Other hot spots (not included in Table 20) showed similar relationships, with surface temperatures ranging from 18°C to 36°C, moisture from 15.7 to 18.1 percent, and damage from 11.0 to 41.7 percent. These surface values, in general, decreased at greater depths, with nearly normal temperatues and damage values at the 6-foot level.

The highest moisture contents consistently were found at locations where hot spot temperatures were the highest. While a pocket of high moisture corn may initially have led to the conditions favorable for mold growth, it is believed that the microbiological heating contributed to the higher moisture content in the area of the hot spots.

Location 1K (Table 20) had a higher percentage of mold-infested kernels at the 4-5 foot level than at the 0-1 foot level, but the damage based on USDA grades at that depth was only 2.0 percent (see Table 20). Kernels can be infested with mold but not considered damaged in the grade factor definition. The temperature and moisture at the 4-5 foot level were also lower than the 0-1 foot and 2-3 foot depths.

Figure 14. Average daily temperatures (°C) near the floor during shipment from New Orleans to Japan, 1986.



Several hot spot locations had lower temperatures on the surface than at the 2-foot or 4-foot levels. Temperatures over 20°C after the surface had cooled could be caused by a higher initial moisture content in the corn at that depth. Active microflora create an increase in temperature despite cooler surroundings.

The moisture content of individual kernels was tested at three depths at one hot spot location in hold 3. The temperature at the 1-foot depth was 23°C, and the sample of corn within the top foot had a range in individual kernel moisture from 14.5 to 21.5 percent (see Figure 17). The samples taken at the 3-foot and 5-foot depths had a lower average moisture and smaller variance among kernels.

Figure 15. Temperature profiles in the vessel at selected depths, Japan, 1986.

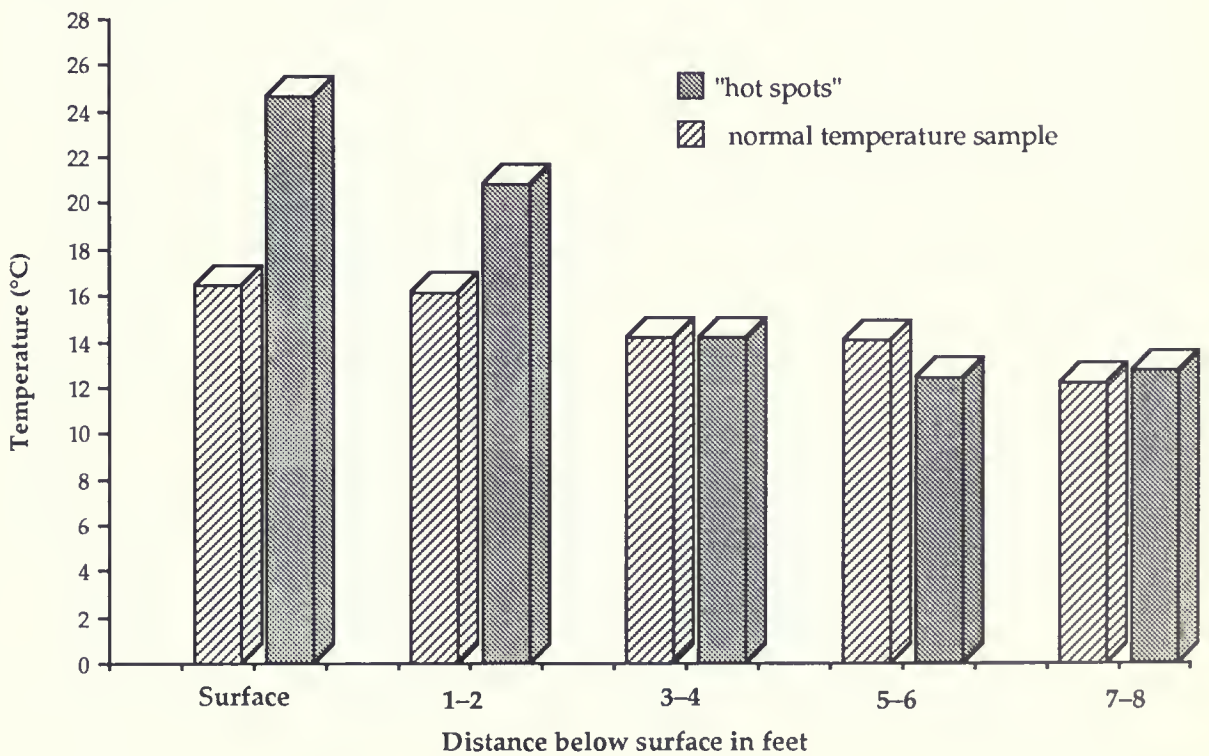


Figure 16. Location of hot spots in hold 3, Japan, 1986.

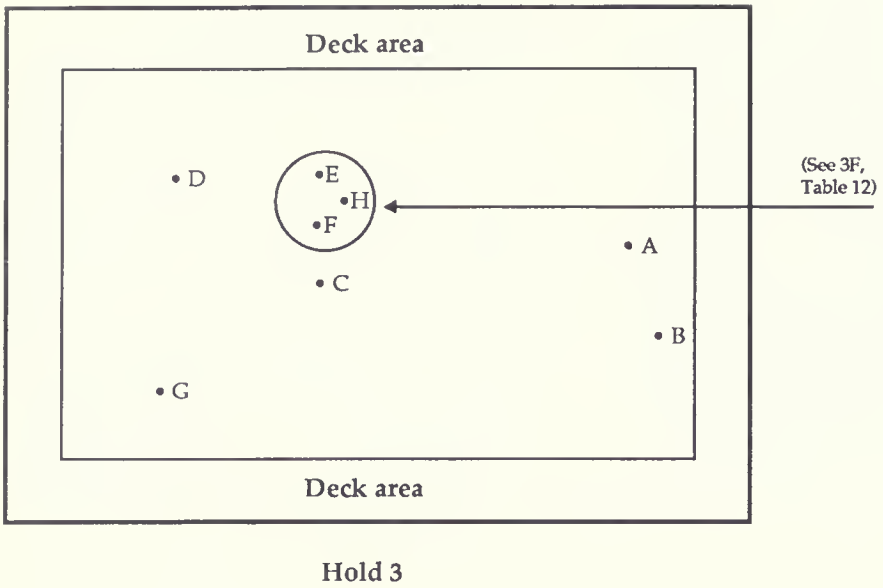
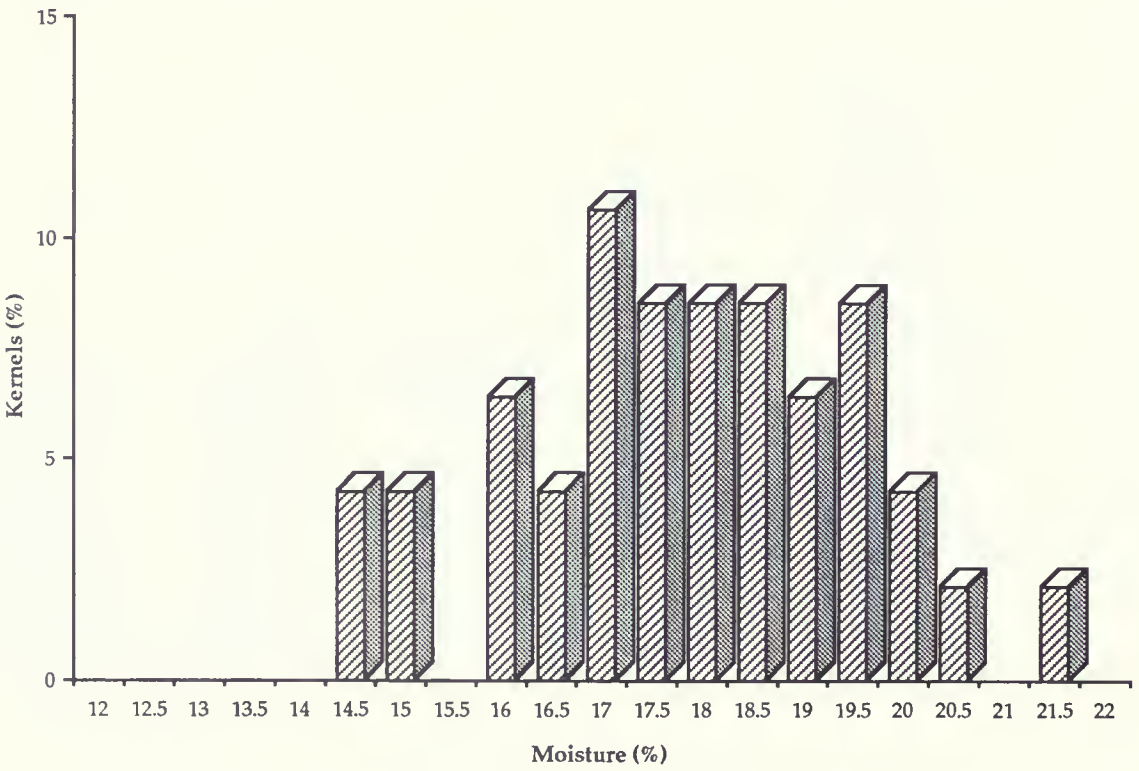


Figure 17. Frequency distribution of individual kernel moisture in vessel hot spot, Japan, 1986.



Summary of Results

The quality of all the corn loaded in the two shipments was equal to or better than the quality specified on the contract on all factors (i.e, No. 3 grade, maximum 15.0 percent moisture). The only factor that deteriorated enough between the origin and destination to lower the grade was BCFM. Moisture content, test weight, and the percentage (by weight) of damaged kernels did not change appreciably during handling and transit.

The increased breakage (a result of impacts during handling) in both shipments generally reduced the percentage of whole kernels, increased the proportion of smaller particles and fine material, and decreased the proportion of larger corn particles. Breakage susceptibility differed widely among samples of corn inbound to the export elevator, but breakage variability decreased during blending to meet the limits on grade factors. A wide range of moisture contents of individual kernels was found in both shipments. Moisture variability among barges was reduced during loading through blending by the export elevator. Some slight reduction in the moisture range and variance occurred during transit in the hold of the vessel, presumably as a result of moisture movement and equilibration among individual kernels. However, some kernels in every sample exceeded the maximum moisture content level needed to ensure safe storage at the temperature to which the grain was exposed. In the 1986 shipment, the analysis of individual kernel moistures indicated that a wide blend of moisture already existed at the time the barges were loaded. The wide range in moisture content did not disappear during the following four weeks in the hold of the vessel. Thus, the basic problem of deterioration related to moisture was already under way when the barges were unloaded into the export elevator.

Temperatures of the sea water surrounding the vessel and air temperatures during the 30- to 35-day voyages were similar in both shipments. There were several examples illustrating the insulating effect of the corn mass, which minimized the influence of temperature changes from sources external to the hold. Extreme changes in external temperature were seldom reflected in corn temperatures for more than three feet from the source; microbiological growth in the corn mass, however, reached levels that generated heat throughout the hold.

Mold growth during the 35-day transit period of the 1985 shipment resulted in grain hot enough to interfere with free flow during unloading. Hot spots in several holds and the percentage of moldy kernels indicated that the same process was under way in the 1986 shipment.

During the four weeks the vessel was on the ocean, mold and fungi continued growth that began in previous exposures. The moisture and temperature conditions were suitable, especially during passage through the Panama Canal, for accelerated growth of mold in the upper layers of every hold. Although the total damage did not change significantly in either shipment during transit, laboratory examination indicated an increase in mold activity. Other signs of quality deterioration included several hot spots being generated within nearly every hold. The hot spots were localized areas of accelerated mold growth, which generated heat and moisture during respiration. The extent of this deterioration was related directly to time, temperature, and moisture conditions within that localized area.

Segregation during loading of the vessels was confined to broken corn and fine materials. The unloading procedures often reduced segregation by drawing grain from several locations simultaneously. The only characteristics showing important segregation were BCFM and particle size.

There were many similarities in the two shipments. In addition to the use of the same ocean vessel, the average moisture levels and the maximum moisture of individual kernels were nearly the same. Both contracts called for No. 3 corn, and the inspection logs showed similar average values for each factor on the

two shipments. When the corn was equilibrated to constant temperature and moisture in the laboratory, the extent of breakage susceptibility was similar for both shipments using samples from the outbound belt. Transit time for the two shipments differed by only three days, and the sequence of air and water temperature changes during the voyage was similar.

There were, however, significant differences in the two shipments at the time of arrival in Japan. The 1985 shipment had much higher temperatures at the destination and more extensive mold growth than the 1986 shipment. In the 1986 shipment the increase in BCFM and smaller particles was much greater. Those differences are related to the beginning corn temperatures at the time of loading and to the higher percentage of kernels with stress cracks in the 1986 shipment. Corn temperatures in the 1985 shipment averaged 22°C the first day after the vessel was loaded. The average temperature in the 1986 shipment was 15°C. Although both shipments were subjected to similar air and ocean temperatures during passage through the Panama Canal, the cooler corn in 1986 reduced microbiological heating within the hold, and the corn at the surface cooled as the air cooled.

Although both shipments contained corn with similar intrinsic breakage susceptibility, in 1986 the colder temperatures during loading impact and the additional handling through shipping bins resulted in an average increase in BCFM between diverter sampler and vessel of 2.73 percentage points. This contrasts with only 1.52 percentage points in the 1985 shipment.

The quality of the corn delivered to Japanese processors in the coasters, barges, or trucks was similar to that loaded on the vessel in New Orleans with the exception of the broken kernels and the change in particle size associated with handling impact. The presence of mold and fungi was not serious enough in either shipment to concern the Japanese processors or to reflect a change in grade. Thus, with the exception of BCFM, the No. 3 yellow corn loaded at New Orleans was delivered as No. 3 yellow corn to the importing elevator in Japan. The factor of BCFM was not only higher on the average for the entire vessel, but because of segregation and relatively small lots being delivered to some processors, the level of BCFM often exceeded the limit for sample grade, but about 2.2 to 2.8 percentage points of BCFM were generated by the unloading, conveying, and reloading procedures at the destination port.

Conclusion

These two case studies are part of a series of five test shipments begun in 1974 [2]. Nine additional vessels of corn were sampled at destination by a diverter sampler installed in an importing elevator and operated by University of Illinois employees over a period of 12 months [3]. Thousands of vessels of corn left U.S. ports during that time period, and the 14 individual case studies do not provide a basis for predicting the average values of breakage, moisture, or increased damage. Rather, this research provides full-scale validation of laboratory results identifying causal factors in quality-losses. The physical relations of moisture, time, temperature, drying conditions, handling methods, and kernel characteristics to quality deterioration have been well documented in controlled experiments. These case studies conducted by the University of Illinois demonstrate to exporters and importers that the relationships hold under operating conditions in the commercial grain market channel and provide more realistic expectations for quality at destination.

The changes in quality that occur between the time the corn is received into an export elevator and the time it is unloaded in the foreign processor's plant have been identified in this study. The results confirm those of previous studies that the major problems are: (a) an excessive number of broken kernels at the destination that, according to official grades, would be labeled broken corn and foreign material; (b) heating and mold growth during the time the vessel is in transit; and (c) segregation on the factors of particle size, broken corn, and moisture within the hold of the vessel during loading and unloading. This study confirmed again that these problems exist despite the corn quality's meeting the contract specifications at the time it was loaded. FGIS data show that the quality of corn is often better than required by the contract at the time the certificate is issued. The primary cause of quality deterioration between the export houses and the foreign destinations is not due to loading substandard quality or to improper inspection, but to normal handling procedures within legal limits of the grades. Corn in these two shipments, loaded under supervision of elevator personnel, FGIS personnel, and University of Illinois researchers from four disciplines, was within the contract grade at the time of loading but was several grades lower on the factor of BCFM by the time it was unloaded at destination.

These studies identified causes of quality deterioration. Excessive breakage during handling in and out of the vessel is caused by corn being highly susceptible to breakage as a result of internal stress cracks. Impacts during loading and unloading increased the breakage and increased the proportion of fine materials and dust. The percentage of whole kernels generally declined with each successive handling.

The problems of mold growth and heating can be attributed to the conditions of time, temperature, and moisture within the hold of the vessel. Blending corn of diverse moisture contents to meet the average of the contract results in a sufficient number of kernels with a high moisture content to create problems during storage and long-distance transport through hot climates. When temperatures in any part of the grain mass reach the critical point, mold growth accelerates. In the 1985 shipment, the corn temperature at the time of loading was 22°C. With the addition of heat during passage through the Panama Canal, microbiological heating as a result of mold growth started in the individual kernels with moisture contents above 17 percent and spread rapidly throughout the entire vessel. In the 1986 shipment, the corn temperature was approximately 15°C at the time of loading, which ensured that the corn never reached sufficiently high temperatures during passage through the Panama Canal to generate serious mold problems during the 33-day voyage. Higher corn temperatures at loading, a longer period of high temperatures through the Panama Canal, or a longer total time in the vessel could have resulted in serious problems with mold and heating in this shipment.

The numerous variables controlling the growth of microflora (including storage history) make it impossible to accurately predict the condition of a shipment at arrival. However, controlling four variables can minimize the risk of spoilage: (a) the average moisture; (b) the maximum moisture of any kernel; (c) the temperature; and (d) the amount of time in transit. The average moisture content is controlled by the contract. Moisture variability is controlled by the practices of country elevators and exporters. The time in the vessel during transit and the temperatures of the corn and outside air are generally beyond the control of either the shipper or the receiver. But the corn temperature (which differs according to the season and the port of loading) should be taken into consideration when setting contract limits on average moisture.

Segregation is a serious problem whenever the vessel or hold is subdivided among different buyers, especially if no effort is made during unloading to blend corn from different holds or different areas of a single hold. Serious segregation problems exist only for broken corn and foreign material. No other factor appears to be severely segregated during loading or unloading. Segregation in the hold of the vessel during loading is unavoidable. But reblending the segregated corn during unloading could reduce the impact of the problem on the final users.

The solutions to these problems lie with the contract specifications of foreign buyers and the practices generated by current U.S. grading and pricing systems. The primary factors under the control of grain handlers could be altered by changing both the contract specifications and the incentives to which grain handlers respond, from farmers to exporters responsible for the final loading of the export vessel.

The research has demonstrated the causes of quality-loss between the time the export certificate is issued at origin and the time of unloading in the foreign processor's plant. Knowing the physical limitations of time, temperature, and moisture and knowing the relationships among drying, handling, and breakage provides answers to the question of how to reduce quality-losses. The physical relationships have been clearly established. However, there are few economic incentives to encourage handlers at each point in the market channel to follow the practices that minimize the quality-losses. The incentives must start with buyers' identifying the relevant factors and factor limits in their contracts and attaching price differentials to these factors. Changes in U.S. grades and marketing practices are also required in order to provide common language and standard measurement technology to help buyers request the desired quality without having to develop a unique contract for each shipment.

Table 1.

Number of samples by hold and layer in the New Orleans to Japan shipment, 1985 and 1986

Hold	Layers sampled	Probes/ sample	Total samples	Metric tons represented by each layer	Metric tons represented by each sample[a]
		1985 at Origin			
5	1, 2, 3, 4, 5	Two-probe	80	1,673	104
6	1, 2, 3	Two-probe	48	1,634	102
		1985 at Destination			
2	1, 2, 4, 5	Two-probe	64	1,673	104
5	1, 2, 3, 4,5	Two-probe	80	1,673	104
6	1, 2, 3, 4	Two-probe	57	1,634	114
2	3	One-probe	36	1,638	45
		1986 at Origin			
1	1, 2, 3, 4	One-probe	144	1,558	43
1	5[b]	One-probe	16	1,558	43
3	1, 2, 3, 4, 5	Two-probe	80	1,748	109
5	1, 2, 3, 4, 5	Two-probe	80	1,752	109
7	1, 2, 3, 4, 5	Two-probe	80	1,667	104
		1986 at Destination			
3	4, 5	Two-probe	32	1,748	109
5	0, 1½, 2, 3-4, 5	Two-probe	80	1,732	108

[a]The metric tons represented by each sample are calculated by dividing the weight of grain in each layer by the number of samples from each layer.

[b]The outside sector under the deck could not be sampled, resulting in 16 samples instead of 36 even though the sampling pattern was that shown in Figure 2.

Table 2.

Changes in grade factors in the market channel from New Orleans to Japan, 1985 and 1986

	Origin						Vessel[d]		Destination[e]	
	Upriver[a]		Barge[b]		Belt[c]		(all holds)		(barge/coaster)	
	No. of samples	Ave.	No. of samples	Ave.	No. of samples	Ave.	No. of samples	Ave.	No. of samples	Ave.
1985										
Grade	–	–	–	–	–	No.3	–	No. 4	–	Sample
BCFM (%)	–	–	–	–	38	3.45	365	4.97*	24	7.68*
Test wt. (lb/bu)	–	–	–	–	38	55.75	359	55.91	24	56.5
DKT total damage (%)	–	–	–	–	38	3.86	–	–	–	–
Moisture[f] (%)	–	–	–	–	38	14.91	361	14.76	24	14.67
1986										
Grade	–	No. 2	–	No. 2	–	No. 3	–	No. 5	–	Sample
BCFM (%)	39	2.90	41	3.10	37	3.86	512	6.59*	36	9.28*
Test wt. (lb/bu)	37	56.15	41	54.42	37	56.43*	512	57.30*	36	57.16
DKT total damage (%)	39	2.43	40	2.66	37	2.25	20	2.50	3	2.10
Moisture[f] (%)	39	14.90	38	14.99	37	14.96	512	14.40*	36	14.53

[a] No data were obtained on origin barges in the 1985 shipment. In 1986, data on barges at time of loading at midwestern river elevators were provided by elevator personnel.

[b] No data were obtained for barges in the 1985 shipment. In 1986, data are based on results provided by the export elevator inspector.

[c] Samples were obtained by the diverter sampler from the outbound belt under FGIS supervision. Each sample represents a 60,000-bushel sublot. Data are those recorded by the Federal Grain Inspection Service on the inspection log.

[d] Data from origin and destination samples are treated as one set of observations. Analysis was conducted at the Agricultural Engineering Grain Quality Laboratory.

[e] Samples were obtained from each of 4 barges (1985) and 3 coasters (1986).

[f] Moisture was removed as a grade determining factor in September 1985 but has been left in this table for purposes of comparison.

* Indicates a statistically significant change from the preceding point in the market channel at the 0.01 level, two-tailed t test.

Table 3.

Average oven moisture[a] at various locations in the market channel from New Orleans to Japan, 1985 and 1986 (%)

	Origin		Vessel[b]	Destination
	Barge	Belt	(all holds)	(barge/coaster)
1985	—	14.67	14.76	14.68
1986	14.47	14.59	14.40*	14.53

[a]Moisture content of all samples was determined by AEGQL using air-oven method, AACC-44-15A.

[b]Data from origin and destination samples are treated as one set of observations.

*Indicates a statistically significant change from the preceding point in the market channel at the 0.01 probability level, two-tailed t test.

Table 4.

Particle-size distribution and percentage of whole kernels at selected points in the market channel from New Orleans to Japan, 1985 and 1986[a]

	Origin		Vessel	Destination
	Barge[b]	Belt[c]	(all holds)[d]	(barge/coaster)
	1985			
Sieve size (inches)[e]				
> 20/64	–	17.06	15.43*	14.91
> 16/64	–	69.76	67.87*	66.28*
> 12/64	–	8.43	8.81	8.64
> 8.5/64	–	2.73	3.34*	3.57
> 6/64	–	1.16	1.97*	2.56*
> 3/64	–	0.66	1.68*	2.60*
Solid pan	–	0.20	0.89*	1.44*
Percentage of whole kernels	–	70.29	70.45	68.23
	1986			
Sieve size (inches)[e]				
> 20/64	21.09	21.27	19.44*	17.71*
> 16/64	66.86	66.68	64.66*	61.21*
> 12/64	6.98	6.61	6.79	6.86
> 8.5/64	2.70	2.87	3.67*	4.51*
> 6/64	1.17	1.36*	2.38*	3.56*
> 3/64	0.86	0.86	2.02*	3.53*
Solid pan	0.34	0.35	1.04*	2.62*
Percentage of whole kernels	80.9	76.3*	71.8*	70.7

[a]Percentages are based on sample weights.

[b]No samples were obtained from barges in the 1985 shipment. In 1986, data are based on diverter samples taken during unloading the barge.

[c]Samples were obtained by the diverter sampler from the outbound belt under FGIS supervision. In 1985 each sample represents a 60,000-bushel sublot. In 1986 each sample represents a 30,000-bushel component.

[d]Data from origin and destination samples are treated as one set of observations.

[e]U.S. Standard Sieves Nos. 5/16, 3, 4, 6, 8, and 16 were used.

*Indicates a statistically significant change from the preceding point in the market channel at the 0.01 probability level, two-tailed t test.

Table 5.

Breakage susceptibility and stress cracks at selected points in the market channel from New Orleans to Japan, 1985 and 1986

	Origin		Vessel[c]	Destination
	Barge[a]	Belt[b]	(all holds)	(barge/coaster)
	1985			
Number of samples	–	24	365	24
Breakage susceptibility[d] (%)	–	17.40	15.80[e]	–
Stress cracks[f] (%)	–	54.17	50.77[e]	48.58
	1986			
Number of samples	41	74	512	36
Breakage susceptibility[d] (%)	17.21	17.06	19.35	22.58*
Stress cracks[f] (%)	62.59	63.24	63.85	66.94

[a]No samples were obtained from barges in the 1985 shipment. In 1986, data are based on diverter samples taken during unloading the barge.

[b]Samples were obtained by the diverter sampler from the outbound belt under FGIS supervision. In 1985 each sample represents a 60,000-bushel sublot. In 1986 each sample represents a 30,000-bushel component.

[c]Data from origin and destination samples are treated as one set of observations.

[d]Percentage passing through a 16/64-inch sieve after impact in a Wisconsin Breakage Tester.

[e]Only 128 samples from the origin vessel were used in 1985 breakage susceptibility tests.

[f]Percentage of kernels with one or more internal fissures in the endosperm.

*Indicates a statistically significant change from the preceding point in the market channel at the 0.01 probabilty level, two-tailed t test.

Table 6.

Changes in the percent of kernels infected with selected fungi during ocean transport, 1986

Species	Average percent of kernels infected			
	Origin	Destination	Change	*t*-value
Aspergillus flavus	1.84	1.12	-0.72	-1.13
Aspergillus glaucus	28.19	33.28	5.09	1.80
Aspergillus wentii	1.28	0.00	-1.28	-4.73
Penicillium	14.44	19.30	4.86	3.93
Fusarium	5.74	8.95	3.21	2.93

Table 7.

Variability in percentage of BCFM from New Orleans to Japan, 1985

	Origin Vessel			Destination Vessel						
	Belt[a]	Hold 5[b]	Hold 6[c]	Hold 2[d]	Hold 5[b]	Hold 6[e]	Hold 2[f]	Single barge[g]	All barges[h]	Individual barges[i]
No. of samples	24.0	80.0	48.0	64.0	80.0	57.0	36.0	6	24.0	4
High sample	4.36	6.88	7.91	11.11	7.78	7.21	15.29	10.78	10.78	8.10
Low sample	2.19	3.00	3.60	2.66	1.97	3.28	1.85	3.92	3.92	7.05
Range in BCFM	2.17	3.88	4.31	8.45	5.81	3.93	13.44	6.86	6.86	1.05
Ave. BCFM	3.26	4.67	5.67	5.20	4.72	5.06	4.66	8.10	7.68	7.68
Standard deviation	0.63	0.91	1.08	1.89	1.03	0.82	2.68	2.55	1.81	.44

[a]Diverter samples of 60,000-bushel sublots, BCFM determined at the University of Illinois.

[b]Two-probe samples from 5 layers of hold 5 at New Orleans and at Japan.

[c]Two-probe samples from 3 layers of hold 6 at New Orleans.

[d]Two-probe samples from hold 2 in layers 1, 2, 4, and 5 at Japan.

[e]Two-probe samples from hold 6 in layers 1, 2, and 3 at Japan.

[f]One-probe samples from hold 2 in layer 3 at Japan.

[g]One-probe samples from 1 barge selected for highest average BCFM.

[h]One-probe samples from all barges.

[i]Based on average BCFM in each of 4 barges, using samples composited from 6 probes.

Table 8.

Variability in percentage of BCFM among samples at selected points in the market channel from New Orleans to Japan, 1986

	Origin Vessel						Destination Vessel				
	Barges[a]	Belt[b]	Hold 1[c]	Hold 3[d]	Hold 5[d]	Hold 7[d]	Hold 3[e]	Hold 5[e]	Single coaster[f]	Individual coaster[g]	All coasters[h]
No. of samples	41	74	160	80	80	80	32	80	12	3	36
High sample	4.01	7.00	14.21	11.24	13.72	10.37	13.21	13.85	16.13	10.35	16.10
Low sample	1.23	2.19	2.60	2.21	3.76	3.24	3.72	4.14	4.89	8.40	4.90
Range in BCFM	2.78	4.81[i]	11.61	9.03	9.96	7.13	9.49	9.71	11.23	1.95	11.20
Ave. BCFM	2.74	4.57	6.58	6.13	7.27	6.12	6.47	7.32	10.34	9.28	9.28
Standard deviation	0.61	1.01	2.35	1.93	2.08	1.53	2.11	1.90	3.28	0.98	2.62

[a] One composite sample per barge taken by diverter during unloading. BCFM determined at the University of Illinois.

[b] Diverter samples representing 30,000-bushel components. BCFM determined at the University of Illinois.

[c] One-probe samples from five layers of hold 1 at New Orleans.

[d] Two-probe samples from five layers of holds 3, 5 and 7 at New Orleans.

[e] Two-probe samples from layers 5 and 4 of hold 3 and from five layers of hold 5 at Japan.

[f] One-probe samples from one coaster selected for highest average BCFM.

[g] Based on average BCFM in each of 3 coasters, using samples composited from 12 probes.

[h] One-probe samples from all coasters.

[i] The range of extreme values among component samples is larger than that of sublots because components were averaged to obtain sublot values reported on the inspection log. The range among sublots was 1.2 percentage points. Therefore, BCFM results using AEGQL procedures for component samples were often outside the limits for sublots and should not be compared with the data on the official certificate.

Table 9.

Variability in percentage of moisture content[a] among samples at selected points in the market channel from New Orleans to Japan, 1985 and 1986

	Origin		Vessel	Destination	
	Barges[b]	Belt[c]	(all holds)[d]	All barges[e]	Individual (brg/cstr)[f]
	1985				
No. of samples	–	24	361	24	4
High sample	–	15.00	15.30	15.00	14.72
Low sample	–	14.40	14.20	14.10	14.52
Range	–	0.60	1.10	0.9	0.20
Average	–	14.67	14.76	14.68	14.68
Standard deviation	–	0.15	0.20	0.18	0.12
	1986				
No. of samples	41	74	512	36	3
High sample	15.50	15.40	15.40	14.80	14.60
Low sample	12.90	13.30	12.80	14.20	14.40
Range	2.60	2.10	2.60	0.60	0.20
Average	14.47	14.59	14.40	14.53	14.53
Standard deviation	0.48	0.40	0.36	0.14	0.11

[a]All moisture values were determined by the 103°C, 72-hour air-oven method at the University of Illinois.

[b]No samples were obtained from barges in the 1985 shipment. In 1986, data are based on diverter samples taken during unloading the barge.

[c]Samples obtained from the belt by FGIS were split with the University of Illinois. In 1985 only 24 of the 38 sublot samples arrived intact. In 1986 the 74 component samples used to construct the 37 sublot samples were analyzed at AEGQL.

[d]Data from origin and destination samples were treated as one set of observations.

[e]Individual probe samples were taken from all barges and coasters.

[f]Based on average moisture in each of four barges (1985) or three coasters (1986). Individual probe data were composited into an average value for each barge or coaster.

Table 10.

Changes in percentage of moisture and BCFM among layers during transit from New Orleans to Japan, 1986

	Moisture (%)			BCFM (%)		
	New Orleans	Japan	Change	New Orleans	Japan	Change
	HOLD 5					
Layer 1[a]	14.42	14.47	+.05	7.4	8.0	+0.6
Layer 2	14.21	14.55	+.34	6.8	7.2	+0.4
Layer 3	14.39	14.44	+.05	8.7	6.3	-2.4
Layer 4	14.54	14.24	-.30	6.1	6.9	+0.8
Layer 5	13.91	13.86	-.05	7.3	8.1	+0.8
	HOLD 3					
Layer 4	13.83	14.06	+.23	6.6	7.1	+0.5
Layer 5	14.60	14.72	+.12	5.8	5.9	+0.1
Ave. all layers	14.27	14.33	+.06	7.0	7.1	+0.1
Ave. layers 4 and 5 (top)	14.22	14.22	-0-	6.5	7.0	+0.6
Ave. layers 1 and 2 (bottom)	14.32	14.51	+.20	7.1	7.6	+0.5

[a]Layers are numbered starting from the bottom of the hold.

Table 11.

Moisture variability in percentage of moisture by 1-foot increments, Japan 1986

Depth from top of hold (ft)	Number of samples	Hold 5		Hold 7
		AEGQL[a]	JBIA[b]	AEGQL[a]
0-1	4	14.50	14.62	14.71
1-2	4	14.50	14.60	14.78
2-3	4	14.46	14.53	14.72
3-4	4	14.38	14.58	14.57
4-5	4	14.41	14.47	14.56
5-6	4	14.43	14.46	14.71
Average	24	14.45	14.54	14.67

[a]Moisture determined by the 103°C, 72-hour air-oven method at the University of Illinois Agricultural Engineering Grain Quality Laboratory.

[b]Moisture determined by the 103°C, 72-hour air-oven method by the Japan Grain Inspection Association Laboratory.

Table 12.

Variability in percentage of moisture content for single kernels of export corn at origin and destination, 1985

Origin

Identification[a]	Moisture (%)[b]	Individual kernel moisture (%)[c]				Standard deviation
		Ave.	Low	High	Range	
SL12,C2	14.7	15.52	12.58	17.70	5.12	0.93
SL12,C4	14.9	15.62	13.02	17.36	4.34	0.75
SL18,C1	14.9	14.91	12.67	16.51	3.84	0.93
SL18,C4	14.9	14.84	12.89	17.39	4.50	0.85
SL19,C4	14.7	14.74	12.88	16.36	3.48	0.74
All samples	14.1	15.62	12.67	17.06	5.12	0.92

Destination

Identification[a]	Moisture (%)[e]	Individual kernel moisture (%)[c]				Standard deviation
		Ave.	Low	High	Range	
H5,L5[d]	14.75	15.27	12.51	16.78	4.27	0.77
H6,L4	14.88	14.89	11.98	16.05	4.07	0.77
H2,L3	14.70	14.80	12.14	16.29	4.05	0.92
H5,L3	14.80	14.96	12.35	16.54	4.19	0.87
Truck	14.68	14.45	13.22	17.70	4.58	0.71
All samples	14.76	14.96	11.98	17.70	5.72	0.85

[a]SL = sublot; C = component in export house. The sampling plan required 15,000-bushel components, combined into 60,000-bushel sublots. Individual kernels were selected from a single "cut" from the diverter sampler.

[b]FGIS moisture on component samples, determined by Motomco.

[c]See Appendix B for a description of the method used in determining the moisture of individual kernels.

[d]H = hold number; L = layer in the vessel.

[e]Moisture was determined using 15 g samples in a 103°C air oven for 72 hours, analyzed concurrently with the individual kernel moisture.

Table 13.

Variability in percentage of whole kernels among samples at selected points in the market channel from New Orleans to Japan, 1985 and 1986

	Origin		Vessel	Destination
	Barges[a]	Belt[b]	(all holds)[c]	(barge/coaster)[d]
	1985			
No. of samples	–	24	365	24
High sample	–	77.60	81.00	76.20
Low sample	–	63.00	55.20	58.60
Range	–	14.60	25.80	17.60
Average	–	70.29	70.63	68.23
Standard deviation	–	4.28	4.41	4.90
	1986			
No. of samples	41	74	512	36
High sample	89.00	86.60	86.00	83.20
Low sample	70.60	67.60	56.20	51.40
Range	18.40	19.00	29.80	31.80
Average	80.93	76.28	71.84	70.74
Standard deviation	4.57	4.29	5.26	5.92

[a]No samples were obtained from barges in the 1985 shipment. In 1986, data are based on diverter samples taken during unloading the barges.

[b]Samples were obtained by the diverter sampler from the outbound belt under FGIS supervision. In 1985 each sample represents a 60,000-bushel sublot. In 1986 each sample represents a 30,000-bushel component.

[c]Data from origin and destination samples are treated as one set of observations.

[d]Individual probe samples were taken from each of the four barges in 1985 and the three coasters in 1986.

Table 14.

Variability in percentage of kernels with stress cracks at selected points in the market channel from New Orleans to Japan, 1985

	Origin Vessel			Destination Vessel				
	Belt[a]	Hold 5[b]	Hold 6[c]	Hold 2[d]	Hold 5[b]	Hold 6[e]	Hold 2[f]	Barge[g]
No. of samples	24	80	48	64	80	57	36	24
High sample	68.0	68.0	72.0	80.0	82.0	70.0	66.0	62.0
Low sample	38.0	26.0	40.0	36.0	28.0	38.0	32.0	28.0
Range in stress cracks	30.0	42.0	32.0	44.0	54.0	32.0	34.0	34.0
Ave. stress cracks percent	54.17	48.85	56.08	51.91	48.28	52.91	48.06	48.58
Standard deviation	6.62	8.70	7.19	8.88	8.39	6.86	7.92	9.66

[a]Diverter samples of 60,000-bushel sublots.

[b]Two-probe samples from five layers of hold 5 at New Orleans and Japan.

[c]Two-probe samples from three layers of hold 6 at New Orleans.

[d]Two-probe samples from hold 2 in layers 1, 2, 4, and 5.

[e]Two-probe samples from hold 6 in layers 1, 2, and 3.

[f]One-probe samples from hold 2, layer 3.

[g]One-probe samples from four barges.

Table 15.

Variability of stress cracks at origin and destination as an indicator of segregation within holds from New Orleans to Japan, 1986

			Origin vessel				Destination vessel		Destination coaster[f]
	Barge[a]	Belt[b]	Hold 1[c]	Hold 3[d]	Hold 5[d]	Hold 7[d]	Hold 3[e]	Hold 5[d]	
No. of samples	41	74	160[g]	80	80	80	32	80	36
High sample	86.0	88.01	90.0	88.0	84.0	90.0	78.0	84.0	76.0
Low sample	30.0	38.0	34.0	50.0	28.0	42.0	48.0	38.0	52.0
Range in stress cracks (%)	56.0	50.0	56.0	38.0	56.0	48.0	30.0	46.0	24.0
Ave. stress cracks (%)	62.59	63.24	61.54	66.78	62.85	65.20	65.13	64.73	66.94
Standard deviation	13.54	10.71	9.52	7.73	11.55	10.98	7.69	9.83	6.33

[a]One composite sample per barge by diverter sampler at New Orleans.

[b]Diverter samples representing 30,000 bushels.

[c]One-probe samples from five layers of hold 1 at New Orleans.

[d]Two-probe samples from five layers in each hold.

[e]Two-probe samples from hold 3, layers 5 and 4 at Japan.

[f]One-probe samples from all coasters.

[g]Only 160 samples were taken because the extreme outside areas of the hold, covered by the deck, could not be reached for probing.

Table 16.

Variability of breakage susceptibility at origin and destination, New Orleans and Japan, 1985 and 1986

	1985		1986			
	Origin		Origin			Destination coasters[f]
	Belt[a]	Vessel[b]	Barge[c]	Belt[d]	Vessel[e]	
No. of samples	24	128	41	74	352	36
High sample	20.90	23.50	28.02	27.04	33.62	26.87
Low sample	14.90	11.10	9.51	10.00	8.85	18.13
Range in breakage susceptibility	6.00	12.40	18.51	17.04	24.77	8.74
Average breakage susceptibility	17.40	15.81	17.21	17.06	18.94	22.58
Standard deviation	1.39	2.75	3.72	3.47	3.53	2.26

[a]Diverter samples of 60,000-bushel sublots.

[b]Two-probe samples from five layers of hold 5 and three layers of hold 6 taken at origin. No data on vessel at destination.

[c]Diverter samples from each barge were provided by the export elevator personnel.

[d]Diverter samples of 30,000-bushel components.

[e]Data from origin and destination samples are treated as one set of observations.

[f]Individual probe samples were taken from each of the three coasters.

Table 17.

Variability of particle sizes at origin and destination, New Orleans and Japan, 1985[a]

	Origin belt[b]			Vessel[c]			Destination Barges		
	High (%)	Low (%)	Sd. dev.	High (%)	Low (%)	Sd. dev.	High(%)	Low (%)	Sd. dev.
Whole kernels	77.60	63.00	4.28	81.00	55.20	4.41	76.20	58.60	4.90
Sieve size (inches)									
➢ 20/64	21.21	14.44	1.80	22.70	11.06	1.67	17.34	13.57	1.00
➢ 16/64	71.93	65.52	1.77	73.72	57.94	2.10	72.78	61.76	2.33
➢ 12/64	9.92	6.70	0.76	12.00	6.64	0.91	10.31	6.51	1.10
➢ 8/64	3.75	2.08	0.42	4.99	2.17	0.43	4.10	2.80	0.39
➢ 6/64	1.66	0.84	0.21	4.36	1.08	0.46	3.49	1.31	0.54
➢ 3/64	1.06	0.37	0.21	6.49	0.37	0.65	4.53	0.66	0.93
Solid pan	0.45	0.05	0.14	5.18	0.14	0.48	3.26	0.26	0.73

[a]Percentages shown represent the material passing through the larger sieves above and held on the sieve indicated. For example, the 1.66 percent of the belt sample held on the 6/64-inch sieve has passed through all of the sieves larger than 6/64 inch.

[b]Samples were obtained by the diverter sampler from the outbound belt under FGIS supervision. Each sample represents a 60,000-bushel sublot.

[c]Data from origin and destination samples are treated as one set of observations.

Table 18.

Variability of particle size at origin and destination, New Orleans and Japan, 1986[a]

	Origin belt[b]			Vessel[c]			Destination Coaster		
	High (%)	Low (%)	Sd. dev.	High (%)	Low (%)	Sd. dev.	High(%)	Low (%)	Sd. dev.
Whole kernels	86.00	67.60	4.29	86.00	56.20	5.26	83.20	51.40	5.92
Sieve size (inches)									
➢ 20/64	29.41	14.27	3.28	28.42	12.07	2.46	20.90	14.63	1.61
➢ 16/64	73.80	59.92	2.82	71.74	55.74	2.86	65.75	53.31	3.00
➢ 12/64	9.90	4.33	1.07	10.02	4.01	0.93	8.30	4.47	0.80
➢ 8/64	4.31	1.81	0.47	5.92	2.34	0.60	5.38	3.66	0.44
➢ 6/64	1.96	0.66	0.30	4.88	0.76	0.64	4.97	2.04	0.68
➢ 3/64	1.43	0.42	0.25	6.20	0.29	0.87	6.51	1.02	1.40
Solid pan	0.68	0.08	0.13	3.64	0.19	0.52	6.49	0.67	1.39

[a]Percentages shown represent the material passing through the larger sieves above and held on the sieve indicated. For example, the 1.96 percent of the belt sample held on the 6/64-inch sieve has passed through all of the sieves larger than 6/64 inch.

[b]Diverter samples of 15,000-bushel components; BCFM determined at the University of Illinois.

[c]Data from origin and destination samples are treated as one set of observations.

Table 19.

Corn temperatures (°C) at selected depths in random locations in the ocean vessel at Japan, 1986

	Depth in feet below the surface of the corn								
Hold	0	0.5	1	2	3	4	5	6	8
1	–[a]	17	15	–	15	–	13	–	–
2	–	16	15	–	13	–	13	–	–
5	–	18	17	–	18	–	17	–	–
6	–	15	14	–	14	–	14	–	–
7	–	17	17	–	15	–	13	–	–
3	21[a]	–	–	20	–	15	–	14	14
4	19[a]	–	–	18	–	15	–	15	14

[a]Temperatures in holds 3 and 4 were measured at 2-foot intervals from the surface to a depth of 8 feet. All other holds were tested at depths of 0.5, 1, 3, and 5 feet.

Table 20.

Temperature and quality characteristics identified in holds 3 and 1 at various depths in the ocean vessel at Japan, 1986

Location[a]	Sample depth (ft)	DKT (%)[b]	Moisture (%)[c]	Temp (°C)	Mold-infested[d] kernels (%)
3F	0-1	29.2	18.1	38	98
	2-3	7.7	15.3	21	88
	4-5	1.0	15.3	12	58
3E	5-6	41.7	18.1	36	78
	2-3	16.7	15.7	24	78
	4-5	1.8	15.5	14	100
1K	0-1	26.3	15.9	23	92
	2-3	25.0	15.3	22	86
	5-6	2.0	15.2	14	98

[a]Location is indicated by hold number and an arbitrary letter assigned to sampling locations distributed across the surface of each hold during the search for hot spots. See Figure 12 for locations in hold 3.

[b]Percentage of total damage graded by official inspector at time of sampling.

[c]Moisture determined by air-oven method at 103°C for 72 hours.

[d]Percentage of kernels showing mold infestation, determined by plating samples in the Plant Pathology Laboratory at the University of Illinois.

Appendix A: Lower Limits of Moisture (%) Needed for Growth of Major Fungi in Cereals

Species or group	Minimum corn moisture (%)[a]
Aspergillus restrictus	14.0 - 14.5
A. glaucus	14.5 - 15.0
A. candidus	15.5 - 16.0
A. ochraceus	15.5 - 16.0
A. flavus	17.0 - 18.0
Penicillium[b]	16.5 - 20.0
Fusarium	22

[a] These values represent the lower limits of moisture needed for the growth of major storage fungi in starchy cereal grains.

[b] Species vary.

Derived from *Storage of Cereal Grains and Their Products*, Volume 5, 3rd ed., 1982. C.M. Christensen, editor, p. 235.

Appendix B: Methodology for Individual Kernel Moisture Determination for Corn[a]

It is of interest to researchers and cereal scientists to detect moisture variability within a grain mass on a kernel-by-kernel basis. The objective of the procedure developed for this study was to provide a mechanism whereby single kernels of corn could be obtained and isolated at any source (e.g., an elevator) and moisture content of individual kernels preserved intact until the assay could be completed. Research is continuing on laboratory and commercial methods for measuring single-kernel moisture, and improved methods have been developed since this project was completed.

Apparatus Needed

- Glass serum bottles, 5 ml capacity, 13 mm openings
- Rubber septa w/aluminum seals for above
- Seal crimper for above
- Air oven (to maintain ± 1°C at 103°C)
- Analytical balance accurate to at least 0.1 mg
- Air tight desiccator with activated alumina
- Permanent marker
- Moisture dishes dried at 130°C for 1 hour, cooled, and tared

Procedure

Glass vials and rubber septa should be number-coded with permanent markers so that a vial septum unit can be maintained throughout the procedure.

Individual kernels should be randomly selected from a grain sample secured and identified by origin. After one kernel is placed in each vial, the coded septum and aluminum seal should be secured to the vial.

A composite sample of about 100 g should be taken from the same lot and placed in an airtight container with identification as to origin and the vial codes from that sample.

Moisture Determination

A. Single kernel.

1. Carefully remove the aluminum seal leaving the rubber septum on the vial.
2. Weigh, to nearest 0.1 mg, the vial, septum, and kernel. Record as "wet gross" weight.
3. Remove the rubber septum and place vial with kernel in a 103°C ± 1°C oven for 72 hours.
4. After drying, replace coded septum on corresponding vial with kernel and move to a desiccator until the vials reach room temperature.
5. Weigh vial, septum, and dried kernel and record as "dry gross" weight.
6. Discard kernel and reweigh vial and septum and record as "dry tare" weight.
7. Calculate moisture content using the equation:

$$\frac{\text{wet gross wt.} - \text{dry gross wt.}}{\text{wet gross wt.} - \text{dry tare wt.}} \times 100$$

Note: *Dry tare weight may be established before sample collection, although it is recommended that dry tare weight be determined at the end of the procedure and wet kernel weight determined by calculation.*

B. Composite sample.

Moisture of the composite mass sample is determined as per AACC 44-15A using approximately 15 g representative whole kernel sample dried at 103°C ± 1°C for 72 hours.

[a] This procedure was developed by Dr. Keith Behnke, Department of Grain Science and Industry, Kansas State University, Manhattan, Kansas.

C. Relationship of kernel weight to moisture determination.

In early experimental stages of a new methodology it is important to search for relationships that could be influencing the accuracy of the variable being measured. In this first test of the methodology a correlation analysis was run on the postshipment samples to determine if a relationship existed between kernel weight and moisture content. The r^2 values ranged from about 0 to -0.4, indicating that no significant relationship exists. The slope of the line was slightly negative, indicating that larger kernels tended to have slightly less moisture than smaller kernels, although the trend was not significant.

Notes

1. Christensen, C.M. 1946. *Cereal Chemistry* 23:322-329. American Association of Cereal Chemists, St. Paul, Minnesota.
2. Hill, Lowell D., Marvin R. Paulsen, and Margaret Early. 1979. *Corn Quality: Changes During Export* (Special Publication 58). Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign.
3. Hill, Lowell D., Marvin R. Paulsen, T.L. Mounts, A.J. Heakin, and G.R. List. 1981. *Changes in Quality of Corn and Soybeans Between United States and England* (Special Publication 63). Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign.
4. Hill, Lowell D., and Marvin R. Paulsen. 1985. *Changes in Quality of Corn Between U.S. and Japan* (AE-4609). Department of Agricultural Economics, Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign.
5. Hill, Lowell D., Marvin R. Paulsen, Terrence J. Kuhn, Barry J. Jacobsen, and Richard A. Weinzierl. 1988. *Corn Quality Changes During Export from the United States to Japan* (AE-4636). Department of Agricultural Economics, Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign.
6. Hurburgh, C.R., Jr. 1984. "Probe Sampling of Corn" in *American Society of Agricultural Engineers* (Paper #84-3019). ASAE: St. Joseph, MI.
7. Hurburgh, C.R., Jr., and C.J. Bern. "Sampling Corn and Soybeans I: Probing Methods." *Transactions of ASAE* 26(3):930-934.
8. Paulsen, M.R., L.D. Hill, and G.C. Shove. 1986. "Temperature of Corn During Ocean Vessel Transport" in *American Society of Agricultural Engineers* (Paper #86-3009). ASAE: St. Joseph, MI.
9. USDA, FGIS. 1987. *U.S. Corn Quality Report, 1986*. Washington, DC.
10. Shove, G.C. 1978. "Wet Grain Aeration for Holding and Drying Shelled Corn" in *Alternatives for Conditioning and Storing Corn at Farm and Elevator* (proceedings of a regional research conference, February 1978), Agricultural Engineering Department, University of Illinois at Urbana-Champaign.

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